CHAPTER ELEVEN

Techniques for Reptiles in Difficult-to-Sample Habitats

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Overview

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This book deals with sampling and other aspects of field research on reptiles. Not surprisingly, the disparities in size and methods of locomotion between reptiles and humans constrain the ability of the latter to sample the former and often interfere with the regular, methodical collection of information (capture or observation) that scientific protocols and methodologies require. The partial or complete inability of humans to negotiate certain types of habitat (e.g., deep water, unstable rock piles, treetops) and/or the ability of reptiles simply to avoid detection and capture in some habitats put humans at a disadvantage compared to reptiles that are well adapted to their particular habitats. In this chapter, we deal with sampling methods and procedures for a subset of habitat types in which we believe reptiles to be especially difficult to sample.

While we do not provide comprehensive coverage of all the difficult-to-sample habitats or reptiles, we present wide taxonomic and geographic coverage, along with a host of references useful for a project designer. We also provide names of individuals from whom additional information on sampling strategies may be sought. Many of the authors represented in this chapter are working to develop novel sampling strategies or to improve existing ones. Without doubt, readers of this chapter will also develop new strategies. Whether reptiles live underwater, underground, high in a forest canopy, sheltered within a mountain of rock, or in some other seemingly inaccessible place, they can be repeatedly and successfully collected and/or detected with methods currently available.

Rock-Dwelling Reptiles

Robert E. Lovich and Aaron M. Bauer

Sampling reptiles in rocky habitats is challenging. The dense and impenetrable nature of piles of rocks and boulders makes it difficult to locate and extract reptiles living within and among them. When searching for or monitoring *saxicolous* reptiles (from the Latin *saxum,* meaning rock, and *–cola,* meaning inhabitant; syn. *rupicolous* from the Latin *rupes,* also meaning rock), it is important to determine how the target species use the habitat and how their natural histories relate to it. Rocky habitats can provide reptiles with protection from predators, refuge from the physical environment, foraging sites (including for preying on other saxicolous animals), and breeding and denning sites; they can also contribute to reptile thermoregulation (Cowles and Bogert 1944; Huey et al. 1989; Webb and Shine 1997, 1998a, 1998b, 2000; Kearney 2002; Shah et al. 2003, 2004; Quirt 2006). Many rock-dwelling species prefer or are completely restricted to a particular type (or types) of rock (e.g., granite, sandstone, limestone, etc.) or rock crevice, because of its size, exposure, thermal qualities, or other features (Schlesinger and Shine 1994a, 1994b; Bauer and Sadlier 2000; Lovich 2001). Indeed, expansive rocky habitats that appear uniform to an untrained human observer generally provide a diversity of discrete types of microhabitat for saxicolous reptiles. The long-term stability of the rock habitat and its evolution are also important considerations. Some

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species require geologically old and stable exfoliating rocks such as those along high ridges or on tops of hills, in contrast to the more dynamic habitats in valleys and canyons that may be seasonally flooded or subject to landslides or tectonic activity in some regions (Lovich 2001).

Prior to sampling an area for saxicolous species, the investigator should thoroughly understand the thermal requirements of the target species and the temperature range and seasons within which it is active. Successful location or monitoring of species can be maximized by searching during their specific daily and seasonal activity periods. Saxicolous habitats can be sampled in a variety of ways. The methods described below are by no means comprehensive, but they should provide an overview of techniques to be considered when developing the sampling plan for a project. Additional information about field techniques relevant to saxicolous reptiles can be found in Simmons (1987, 2002) and Bennett (1999), and in Chapter 5, "Finding and Capturing Reptiles," and Chapter 13, "Standard Techniques for Inventory and Monitoring," in this volume. The specific sampling method or methods to be used should be chosen carefully to maximize sampling efficiency.

Rock Flipping

Manual rock flipping is a popular and widely used method for sampling reptiles in saxicolous habitats. This method involves moving or lifting rocks—including rock sheets or flakes—to expose reptiles that may be hidden beneath or within them. Rock flipping is most useful when collecting specimens, but the technique can be used to gather baseline data or to compile a species list for a particular area. It is an effective way for a surveyor to search through rocks at the surface or subsurface level, and it has been utilized extensively by herpetologists. When employing this method, investigators should consider and record the microhabitat used by the target species, because many reptiles prefer particular types of rock-crevice habitat (Figs. 55 and 56). Whether the rocks lie on dirt or on other rocks, whether they are vertical or horizontal, their slopes, aspects, and thermal characteristics, as well as the amount of space beneath them, are all important considerations that can help to maximize search efficiency and minimize search effort and habitat disturbance when looking for specific species. Field investigators should also be aware that repeated sampling or collecting in the same rocky habitats has been shown to result in fewer reptiles and decreased relative abundance, and to have impacts on reptile species, sex, age-class, and seasonal use (Goode et al. 2004, 2005).

One constraint on rock flipping is the size of rock that the surveyor can lift. Large rocks or boulders, as well as smaller rocks deeply buried in their surrounding substrates, may be immovable. Rock flipping is generally not useful for long-term monitoring studies, because maintaining the integrity of the habitat and a high likelihood of recapturing the same individual reptiles after the habitat is repeatedly disturbed can be difficult (Schlesinger and Shine 1994a, 1994b; Goode et al. 2004, 2005).

Tools such as crowbars and pry bars are sometimes used to facilitate manual movement of rocks that would otherwise be unmovable. Use of such tools disturbs and can destroy features of rocky habitats, and we do not recommend employing such methods except under special circumstances (e.g., salvage sampling). In many regions of the world, governing agencies expressly forbid the use of equipment to break or move rock piles for collecting purposes. An investigator should thoroughly review local laws and regulations before using any tools to facilitate sampling. The surveyor should be mindful that rock flipping, in addition to needlessly degrading or destroying habitats when recklessly employed, is potentially detrimental to resident species in other ways. Accidentally crushing animals when lifting or moving rocks is always a possibility; however, crushing what lies beneath a rock can be minimized by lifting the rock slowly and cautiously and looking for reptiles underneath, as you lift. After a rock is lifted a few centimeters, it can be wedged in position with a small stone and the area underneath it searched with the aid of a flashlight or mirror. Many rocky habitats are the result of thousands of years of weathering, and moving rocks that are tightly pressed together can break the moisture seal created by mosses, lichens, and detritus that have accumulated along the rock margins. A moisture seal can be critical for animals trying to avoid desiccation, and it can insulate them from extreme outside temperatures. It can also prevent rainwater from periodically flooding a rocky refugium. Once a rock is removed from its original location, the microhabitat that was present beneath it will be altered significantly. Habitat disruption can be minimized if rocks that are moved are returned to their original positions. We exhort anyone using manual rock flipping methods to "always put the rocks back!"

Visual Surveys

Investigators carry out visual surveys for saxicolous species to document the presence or absence of species as part of transect surveys, visual encounter surveys, or other monitoring protocols (see Chapter 13, "Standard Techniques for Inventory and Monitoring"). Simply walking through an area and noting the location of reptiles during the day or at night can provide data on species' distributions and their presences or absences at particular sites or in particular microhabitats. Such data can be used to develop a reptile species list for an area. Reptile sign, such as feces or shed skin, can also be used to identify the presence of certain species. Droppings at or near the apex of exposed rocks with a view often signal the presence of males of territorial diurnal lizards. In contrast, large accumulations of feces or nitrogenous waste near crevice openings or overhangs suggest the presence of nocturnal forms, such as geckos. Rupicolous snakes often use crevices or rock edges to assist in the removal of skin in ecdysis. Shed skins found in crevices or between rocks can provide species-level identification if they are reasonably intact.

Lantern walking at night is a widely used and effective method for monitoring nocturnal and/or crepuscular reptiles in saxicolous habitats. This method involves illuminating habitats at night while searching for resident reptiles. Lantern walking is especially useful for collecting or simply for documenting the presence of nocturnal species at a site. Although this technique is most useful for monitoring nocturnal species, it can also be used to detect sleeping or inactive individuals of diurnal species. Lantern walking can be used as a type of visual transect survey or simply to augment diurnal visual surveys or other sampling methods. Many artificial-light sources are available commercially, including battery-operated headlamps, gas lanterns, flashlights, and rechargeable lights

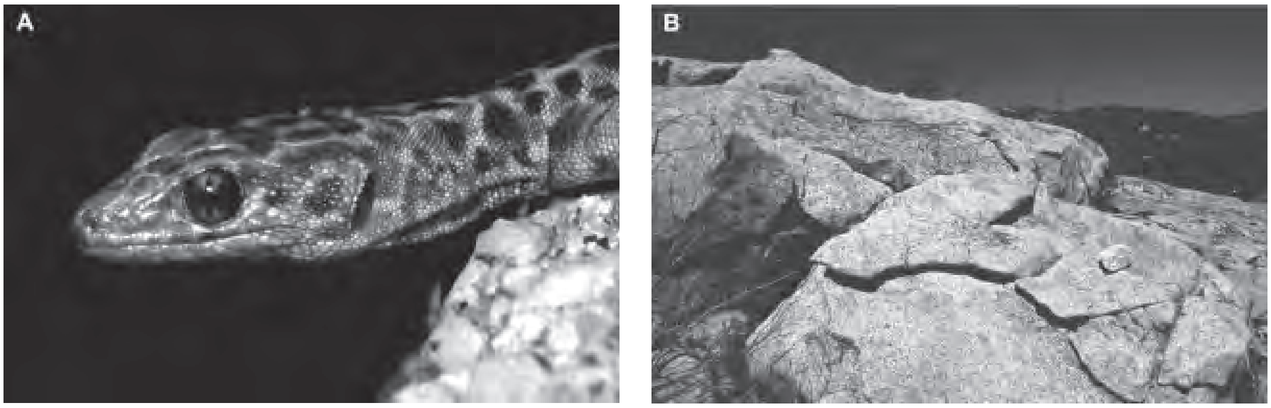


FIGURE 55 (A) Head of an adult Granite Night Lizard (*Xantusia henshawi*). Note the dorsoventrally compressed body typical of crevice-dwelling reptiles. (B) Rocky outcrop in San Diego County, California, which is typical habitat for Granite Night Lizard, Granite Spiny Lizard (*Sceloporus orcutti*), Rosy Boa (*Lichanura trivirgata*), Speckled Rattlesnake (*Crotalus mitchellii*), and other reptile species. (Photos by R. Lovich.)

FIGURE 56 Northern Bahamian Rock Iguana (*Cyclura cychlura*) emerging from a crevice in its rocky outcrop habitat on San Salvador Island in the Bahamas. (Photo courtesy of R. Toft ©, reprinted with permission.)

of various types. The artificial-light source selected should provide adequate illumination to detect the target species and yet be of a size suitable for the surveyor to carry during the rigors of fieldwork.

Alternatively, an investigator can use a night-vision device that operates either by magnifying ambient light or supplementing it with infrared light. Night-vision devices are available in monocular or binocular form and can be worn as goggles with a head mount. Newer-generation devices may allow investigators to identify species; older (and more affordable) models lack the resolution to permit such identification, although they can be used effectively to scan rock faces or crevice openings for reptile activity.

Noosing is a method in which a simple loop of string, dental floss, or light-test fishing line fastened to the end of a rod or pole is used to capture reptiles (but see "Noosing," in Chapter 5). This method is most useful for relatively small tetrapod reptiles. Snakes, turtles, and other reptiles are too narrow, too wide, too heavy, or otherwise not well suited for capture by this method. Many reptiles, although wary of humans, will allow an observer to approach to within some limited distance. By understanding and respecting the approach distance for a target species and employing a little stealth, an observer can usually get close enough to noose the animal. A pole of the required length with a noose at the end can be lowered and drawn around the neck of the reptile. At the moment the noose is lowered over the reptile's head, the rod is jerked upward, and the noose tightens around the neck of the reptile, allowing it to be captured in a safe and effective fashion. Noosing rarely causes injury, although occasionally an animal will choke or be hurt while dangling from the noose. To prevent asphyxiation or other harm, reptiles should be removed from the noose as soon as possible and then processed. Soft-skinned species or those capable of gripping tightly to the substrate (e.g., geckos) are best noosed and then lifted from the substrate by hand.

In enclosed rocky spaces or rock crevices, a modified noose is most effective. A stout fishing line is doubled over and passed through a short (approx. 30–40 cm), stiff copper tube. The distal end of the tube is crimped so as to allow the bend of the fishing line to act as a noose when pulled from the proximal end. The noose must be stiff enough to retain its rigidity but ductile enough to permit bending to accommodate the architecture of a particular crevice. With the noose pulled taught, the copper tube serves as an effective crevice probe. The use of hooks to remove larger lizards from crevices is documented in Bedford et al. (1995).

Firearms and Projectiles

Another method, used primarily for collecting reptiles, is to shoot a target organism. The type of gun used should be chosen to maximize successful capture of the target species while minimizing the amount damage to the specimen. This method is controversial and potentially dangerous, or even lethal, both to the target species and the surveyor. The use of any type of gun for monitoring or field collection should be well justified and carefully planned in advance, with safety as the highest priority for all parties involved.

Air-powered and higher caliber guns are extremely effective for the capture of reptiles, but they are dangerous to the reptiles, surveyor, and other persons and animals in the area. Because guns can cause damage to the specimen, the surveyor should choose a caliber appropriate for the capturing the specific target reptile while minimizing the amount of damage to it. We highly recommended that anyone using firearms take a gun safety course and review carefully and adhere to local gun laws and regulations. Some countries expressly forbid the use or possession of any type of gun, and nearly all countries strongly regulate possession and/or use of firearms.

For millennia, indigenous peoples around the world have used blowguns and bows and arrows to capture reptiles. An investigator working in an area inhabited by indigenous people should consult them about methods for finding and capturing reptiles (see also "Collaboration with Local People for Sampling Reptiles," in Chapter 5). For blowguns on the commercial market, one can purchase both lethal (pointed-tips) and nonlethal (blunt-tipped) projectiles. Both types are useful for capturing reptiles in a variety of habitats (see "Arboreal Reptiles," below), including saxicolous habitats. The blowgun and projectile to be used should be selected after careful consideration of their functions and the objectives of the study.

Researchers can effectively collect small reptiles (≤20 g) by shooting them with rubber bands. Large, broad bands (size 107) are particularly effective when shot off of the thumb or forefinger and, depending on the skill of the collector, can be used to stun or kill lizards at distances of up to about 6 m. Rubber band guns (single- or multiple-band models) are also available commercially. Such guns tend to be quite accurate at ranges even greater than 6 m, but because they use much thinner rubber bands, they are not as effective as collecting tools. Rubber bands are cheap, quiet, safe, and reusable. In order to relocate used bands, it is advisable to mark them with bright colors that will stand out against a typical rocky background. Because "rubber-banding" is associated with high mortality rates (Vargas et al. 2000), the technique is not appropriate for long-term studies or recapture surveys.

Trapping

Pitfall trapping is a method widely used to sample terrestrial vertebrates (see "Funnel Traps, Pitfall Traps, and Drift Fences," in Chapter 5, and "Pitfall-Trap Surveys," in Chapter 13) and has been employed in many areas around the world. However, the efficacy of this sampling method for capturing saxicolous reptiles is questionable. For one thing, the habitats of many saxicolous species are so specialized that an animal seldom ventures far from its home area. Second, pitfall traps are usually placed in areas where holes can be dug deep enough for the traps to be set, which generally excludes rocky areas. Thus, saxicolous species cannot be captured reliably using this method. Given the large amounts of time, person-hours, and costs of such sampling, we do not recommend it for sampling exclusively saxicolous reptiles.

The use of "sticky traps" (also known as "glue traps") designed and marketed for the capture of pest insects and rodents is an alternative trapping method that can be useful for the capture of some saxicolous reptiles (Bauer and Sadlier 1992; Rodda et al. 1993). Sticky traps can be placed near the entrance to crevices or in other potentially "high traffic" areas. Traps should be checked at least once a day, as entrapped reptiles are susceptible to heat stress, dehydration, and predation by ants, arthropods, and other vertebrates (which themselves may become trapped; Glor et al. 2000). Animals can be removed from traps by gently coating them with vegetable oil and working them free of the glue. Although mortality rates from glue trapping are reportedly high (Glor et al. 2000; Vargas et al. 2000), prompt and careful checking and cleaning of the traps minimize injury and death. Because the efficacy of glue traps decreases with the accumulation of sand, soil, and/or moisture on the adhesive surface, these devices are inappropriate for long-term trapping programs unless they can be replaced at frequent intervals.

Traps can be baited in some circumstances, especially for species that respond to fruit, carrion, live arthropods, or live vertebrate prey. Baiting has been used successfully in conjunction with glue trapping for saxicolous lizards of the genus *Platysaurus* (flat lizards; Whiting 1998) as well as for *Eulamprus quoyii* (Eastern Water Skink) from rock crevices along creeks (Downes and Borges 1998). Under such circumstances, traps placed close to a crevice or retreat entrance may be the most successful. Other techniques reported to be effective for some rupicolous forms are adhesive devices or grips at the ends of poles, sticks, or tubes slender enough to enter narrow crevices (Durtsche 1996).

Coverboards (see "Sampling with Artificial Cover," in Chapter 13), have been shown to be effective as a method of estimating reptile and amphibian biodiversity (Grant et al. 1992) and of capturing a variety of species (Hoyer and Stewart 2000). Potentially, the boards could be used to attract saxicolous species if placed against, upon, or adjacent to rocky habitats. However, the method has not been widely used to sample rocky habitats, so little is known about its efficacy with respect to saxicolous species. Nevertheless, coverboards are inexpensive, require little maintenance, and may be useful when deployed in conjunction with other sampling methods. The size, thickness, and substance of the coverboard must be carefully selected to ensure an appropriate thermal regime (e.g., metallic and/or very thin materials should be avoided) and permanence (e.g., boards made of light, low-density, or high-profile materials may blow away in

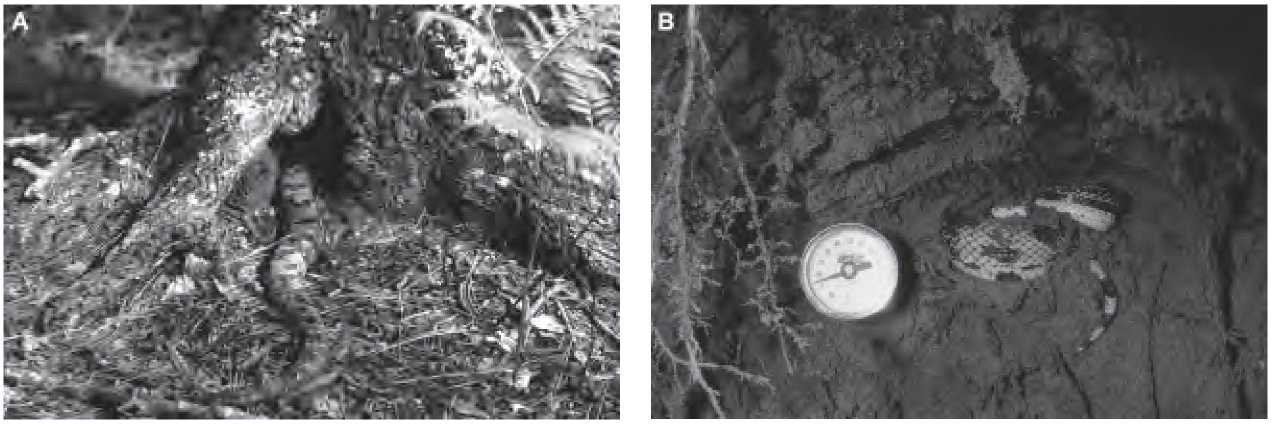


FIGURE 57 (A) Timber Rattlesnake (*Crotalus horridus*) entering a den, Pine Barrens, New Jersey. (B) Pinesnake (*Pituophis melanoleucus*) in hibernation within a den. (Photos by R. T. Zappalorti.)

high winds) and to meet other significant needs of the target species.

Conclusions

Effective sampling for saxicolous reptiles begins with a thorough knowledge of the diversity of rocky microhabitats and the thermal and retreat requirements of the taxa likely to occur in the survey area. Capture and survey techniques include potentially habitat-destructive investigation of retreat sites and less invasive, but perhaps less effective, day and night searches and/or trapping for surface-active reptiles. Because rocky elements in many habitats are too large to be moved and too tightly packed to permit easy human access, most capture techniques require the use of extended-reach (e.g., poles, nooses) or projectile (e.g., rubber bands, dust shot) devices. Use of a combination of the techniques outlined above will likely result in a representative sample. If the diversity of local rock-living reptiles is low (e.g., in some cool temperate regions) or restricted to only one or two microhabitats (e.g., in geologically simple areas of low substrate diversity), however, one or two techniques especially suited to the expected species should suffice.

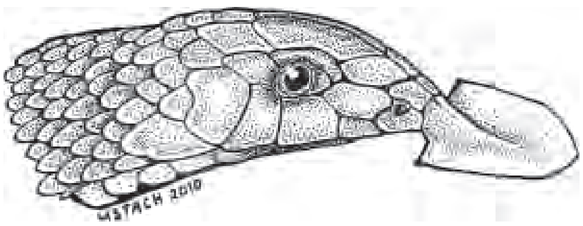
Snake Hibernacula and Communal Denning

Robert N. Reed, Cameron A. Young, and Robert T. Zappalorti

Many species of reptiles in temperate zones or at high elevations in subtropical and tropical areas avoid the thermal stresses of winter by hibernating below the frost line in underground chambers or dens called hibernacula. The reptiles may hibernate singly (Fig. 57) or aggregate in monospecific or heterospecific groups (Parker and Brown 1973; Gregory 1974). Communal denning in hibernacula is an important part of the seasonal activity cycles of some species of reptiles, especially snakes (Gregory 1984a and references therein), but also of some lizards (Congdon et al. 1979) and turtles (Carpenter 1957). Studies conducted at hibernacula can record species presence and, thus, contribute to measures of local community richness and evenness; they can also provide data on population size and demography, activity cycles, and thermal characteristics of hibernating animals (Brown and Parker 1982; Graves and Duvall 1987, 1990). Observing or capturing populations or demes at communal hibernacula allows a researcher to rigorously investigate topics such as thermal tolerances (Brown et al. 1974; Jacob and Painter 1980; Sexton and Hunt 1980; Weatherhead 1989); rates of winter mortality (Hirth 1966; Shine, LeMaster et al. 2001) and juvenile survival (Brown et al. 2007); courtship and mating behaviors (Shine et al. 2000); and movement patterns into and away from hibernacula (Reinert and Zappalorti 1988a, 1988b; Shine, Elphick et al. 2001; Wallace and Diller 2001); as well as to compare results among species (Parker and Brown 1973).

We define a *hibernaculum* (or den) as any retreat protected from subfreezing temperatures, in which reptiles spend the winter. Typically, hibernacula are not created by the target reptile, so determining occupancy of a chamber is more important than simply locating it. Consider a tortoise burrow or a coyote scat; these items provide definitive evidence that a tortoise or coyote, respectively, was present at the site at some point. A hole in the ground, in contrast, may or may not be (or have been) a snake hibernaculum. Consequently, determining occupancy of a potential hibernaculum is vital. This is typically accomplished by observing reptiles directly during ingress or egress, with remote-viewing devices, or via other means (e.g., burrow cameras).

Natural chambers that could be used as hibernacula are found in a variety of places and habitats, including rock piles (Parker and Brown 1973), sinkholes (Gregory 1974; Shine, Elphick et al. 2001), hollow trees (Kauffeld 1957), holes left by rotting tree stumps (Viitanen 1967), caves (Drda 1968; Sexton and Hunt 1980), crevices in shale (Bothner 1963) or limestone (Shine et al. 2000), ant mounds (Criddle 1937; Carpenter 1953), abandoned rodent burrows (Cohen 1948; Carpenter 1953; Viitanen 1967; Plummer 2002), and the burrows of prairie dogs (Klauber 1972; Holycross 1995), foxes (Zappalorti et al. 1983), skunks (Zappalorti et al. 1983), gopher tortoises (Moler 1992), and crayfish (Carpenter 1953; Kingsbury and Coppola 2000). Most reptile species use suitable natural crevices or openings as overwintering sites (Woodbury 1951; Viitanen 1967), although some species of snakes can excavate their own burrows (Platt 1969; Carpenter 1982; Burger et al. 1988). Reptiles can also use spaces in or under human-made structures such as railroad beds and ties (Zappalorti and Reinert 1994), old wells (Brown et al. 1974), abandoned dump sites, abandoned mines (A. T. Holycross, pers. comm.), and buried debris



from land-clearing operations (Zappalorti and Reinert 1994), as hibernacula. It is also possible to construct artificial dens in suitable areas as conservation measures (Zappalorti and Reinert 1994; Showler et al. 2005) or specifically for observational studies of hibernating snakes (Gillingham and Carpenter 1978).

Only a small subset of this wide range of hibernaculum types is communal, containing large numbers of individuals. Despite their comparative rarity, communal hibernacula are of particular ecological and conservation interest, especially because they are typically used year after year by the same individuals (Woodbury and Hansen 1950; Brown 2008). Sampling the snakes in hibernacula can provide a demographic characterization of a population that approaches one obtained from a complete census. In addition, locating such hibernacula allows one to delimit critical winter range for species of concern for potential protection. Communal dens typically occur at high latitudes or high elevations where winter refugia that allow snakes or other reptiles to avoid freezing temperatures are rare. In the northeastern United States, Timber Rattlesnakes (*Crotalus horridus*) hibernate communally on south-facing slopes with abundant rock outcrops, where deep fissures lead to below-ground crevices (Galligan and Dunson 1979; Brown 1993). In Manitoba, Canada, garter snakes congregate below the frost line in huge numbers (in excess of 50,000 snakes) in large limestone sinkholes and caverns (Gregory 1974; Shine, Elphick et al. 2001). In western portions of North America, multispecies communal dens can be found on southeast facing slopes at high elevations (Parker and Brown 1980). Unfortunately, in various areas snakes that occupy communal dens are persecuted or harvested, especially rattlesnakes. Typically, the snakes are killed for "sport" (e.g., at "rattlesnake round-up" events), occasionally for food, or out of fear due to popular misconceptions about the human health hazards that these species pose (Brown 1993; Fitzgerald and Painter 2000).

Finding and Sampling at Hibernacula

In the following paragraphs, we discuss various tools that are useful for both detecting hibernacula and sampling any reptiles that occupy them. That the majority of studies of communally denning reptiles have focused on snakes is reflected in our recommendations for locating, monitoring, and sampling at hibernacula. A greater proportion of a local population than is typical of many reptile studies may be captured at hibernacula, especially at communal hibernacula used by all age classes. This does not mean, however, that sampling at hibernacula will necessarily produce a reliable census of a population. Any of the numerous typical analytical problems associated with estimating population sizes of reptiles may apply (e.g., age-, stage-, or sex-based variation in detection probability, observer bias, temporal variability; see Chapter 15, "Population Size and Demographics," for a discussion of these issues).

REMOTE SENSING

Aerial photography, infrared photography, and light detection and ranging (LIDAR) are remote-sensing methods that can be used to locate potential denning sites. In addition, geographic information system (GIS) technologies can be used to identify or analyze various features of a den site and surrounding areas, including land use, habitat type and characteristics, developments, wetland and water bodies, and topography. Dens located through these methods can then be ground-truthed and investigated by specialized surveys (described below) at these sites to ascertain whether potential hibernacula are occupied and to identify species use of the den.

PEDESTRIAN SURVEYS

Pedestrian surveys are often used to locate hibernacula (Brown and Parker 1976a; Reinert 1992; Zappalorti and Reinert 1994; Prior and Weatherhead 1996; Kingsbury and Coppola 2000). In pedestrian surveys investigators walk slowly through potential denning habitats (as described above) looking for snakes; a survey can be time- or area-constrained, or opportunistic (see "Visual Encounter Surveys," in Chapter 13). Such surveys can have high observer bias and therefore should be carried out by qualified biologists with target-species experience. These searches should be scheduled during appropriate seasons, times of day, and weather conditions, as snakes may be present at the entrance of a hibernaculum only briefly depending on temperature and other factors. Prior to initiating fieldwork, investigators should thoroughly review publications on the natural history of the target species to determine the appropriate temporal search window.

RADIOTELEMETRY

Radiotelemetry is one of the most productive ways of locating den sites, as snakes implanted with radiotransmitters during summer months can be followed to hibernacula in the fall (Reinert and Zappalorti 1988b). However, radiotelemetry requires expensive equipment and extensive personnel time. Once a hibernaculum is found, investigators can apply various capture techniques at the den to determine species composition, individual numbers, and occupancy rates.

VISUAL MONITORING

Known den sites can be visited during the appropriate temporal windows to detect snake occupancy visually. Investigators should ensure that repeated visits to a hibernaculum do not alter the behavior of the inhabitants or damage the den site (Brown 1993). For example, investigators visually monitoring a historic den site should hide in a blind placed to minimize disturbance and alteration of snake behavior. Visual monitoring requires significant time and personnel but can reveal the current status of a hibernaculum and provide accurate data on species and numbers of individuals present and on activity patterns. Biologists with limited target-species experience may not be qualified to carry out visual monitoring, because of the cryptic nature and camouflage of many snake species as well as observer biases that are difficult to quantify (but see Rodda 1993). If the only information required is confirmation of occupancy, burrow cameras may be used to investigate the interior of a hibernaculum, although such surveys may also have biases (Smith et al. 2005).

CONFINEMENT TRAPS

Confinement traps can be used with known or suspected hibernacula that are small, such as rodent burrows, crayfish burrows, or ant mounds, and that are not likely to contain many snakes (Carpenter 1953). These traps confine snakes exiting hibernacula to small arenas so that they can be differentiated from snakes entering the hibernacula. A series of fences and one-way funnel traps are constructed as follows: (1) The entire entrance hole or hole complex is surrounded by a cone of small-mesh hardware cloth or equivalent. The cone is placed over the entrance hole and the large end of the cone is buried at least 10 cm into the ground so as to prevent ingress or egress. (2) The trap is enclosed with an exclusion fence placed approximately 1 m from the cone, with several small one-way entrance funnels at ground level to allow entry from the exterior to the arena between the exclusion fence and the confinement cone. Snakes returning to the hibernaculum circle the exclusion fence and enter through the funnels, but the inner cone blocks ingress into the hibernaculum. The combination of the two confinement areas allows investigators to distinguish between snakes exiting the hole and snakes attempting to enter to hole. Adding a one-way exit flap (e.g., Rodda, Fritts, Clark et al. 1999) at the level of the hole but inside the internal cone could potentially reduce the number of exiting snakes that reenter the hole and escape detection, but to our knowledge this type of modification has not been field tested. Although infrequently used in recent times, this type of trap could be very effective for determining use of a known or suspected small hibernaculum. However, small confinement traps are not appropriate for large denning areas with potentially huge numbers of snakes; for such large dens, drift fences are more practical.

DRIFT FENCES AND PITFALL TRAPS

Drift fences can be used to catch snakes either entering or leaving a den. Dens surrounded with drift fences in the late winter facilitate capture of snakes emerging from hibernation (Brown and Parker 1982; Wallace and Diller 2001); in the fall and spring, they intercept snakes moving into and out of the den (Brown and Parker 1976a). Installing a drift fence around the entirety of a large den or den complex is labor intensive, but once the fence is established, it creates an opportunity to collect information on the entire denning population. Drift fences are typically constructed of aluminum flashing material, commercial silt fencing, or small-mesh hardware cloth. For studies that use drift fences and confinement cones, one assumes that no animals escape detection or climb over or burrow under the fence. These assumptions can be validated if the fence is properly installed and a mark-recapture protocol is employed. Drift fences should be buried to a depth of at least 10 cm and should have enough pitfall or intercept traps to capture most animals on both sides of the fence. Fence height will be determined by the size and habits of the target species and goals of the study. For example, a fence designed to contain snakes of large arboreal species will be much higher than one intended to contain small fossorial species. Folding over several centimeters at the top margin of the fence to form an overhanging barrier will often prevent snakes from climbing over a low fence. Additional information on traps and drift fences can be found in "Funnel Traps, Pitfall Traps, and Drift Fences," in Chapter 5, and under "Pitfall-Trap Surveys," in Chapter 13.

Several different types of traps, each with its own advantages and disadvantages, can be placed along drift fences to capture reptiles. Round funnel traps made of window screening are typically difficult to fit flush against a fence but can be bent and adjusted to fit around rocks and other features of many sites. In flat, even terrain, box traps are generally superior to round funnel traps. The former can be placed on both sides of a fence to determine ingress and egress of snakes. Another option is to cut a hole in a fence and place a box trap on one side; this setup provides a dark ingress/egress opening that can be attractive to snakes moving along the fence. A one-way door or flap installed on a box-trap funnel will decrease the number of snakes escaping (Rodda, Fritts, Clark et al. 1999). Both funnel traps and box traps should be checked at least daily and before any severe (extremely cold or hot) weather.

Another alternative is to place coverboards (Grant et al. 1992), paving blocks (Webb and Shine 2000), or similar objects along a fence to provide artificial cover or basking platforms for snakes entering or exiting a den. Coverboards do not have to be checked daily because they do not confine the snake inside a trap. Therefore, if a drift fence is monitored irregularly, coverboards should be used instead of funnel or box traps (see "Sampling with Artificial Cover," in Chapter 13).

If a single discrete entrance to a den has been identified, it may be possible to attach a large hose or pipe (rubber, PVC, or plastic) to the entrance with duct tape or other adhesive, directing emerging snakes into a corral or large trap with a one-way door (Klauber 1972). As with other confinement traps, these should be checked daily and when any extreme temperature conditions are expected. Additional information on traps and trapping is provided in Chapter 5, "Finding and Capturing Reptiles."

Monitoring Techniques

Monitoring and sampling at hibernation sites are most easily carried out in the early spring, before emergence begins, especially on warm days (>10°C), when basking may occur (Vetas 1951; Jacob and Painter 1980; Sexton and Hunt 1980). Monitoring should continue until all snakes have exited the den. As temperatures increase, traps should be checked daily to ensure that dates of emergence are recorded accurately and to prevent mortality from unexpected extreme temperatures. Fall sampling should begin when daily minimum temperatures fall below the preferred activity temperatures of the study organisms.

Passive Integrated Transponders (PIT tags; Gibbons and Andrews 2004), radioactive markers, and fluorescent dyes can all be used to monitor activity at a snake den. For example, automated systems can record snakes that have been captured and implanted with PIT tags (see "Permanent and Temporary Tags," in Chapter 9) whenever they enter or leave a

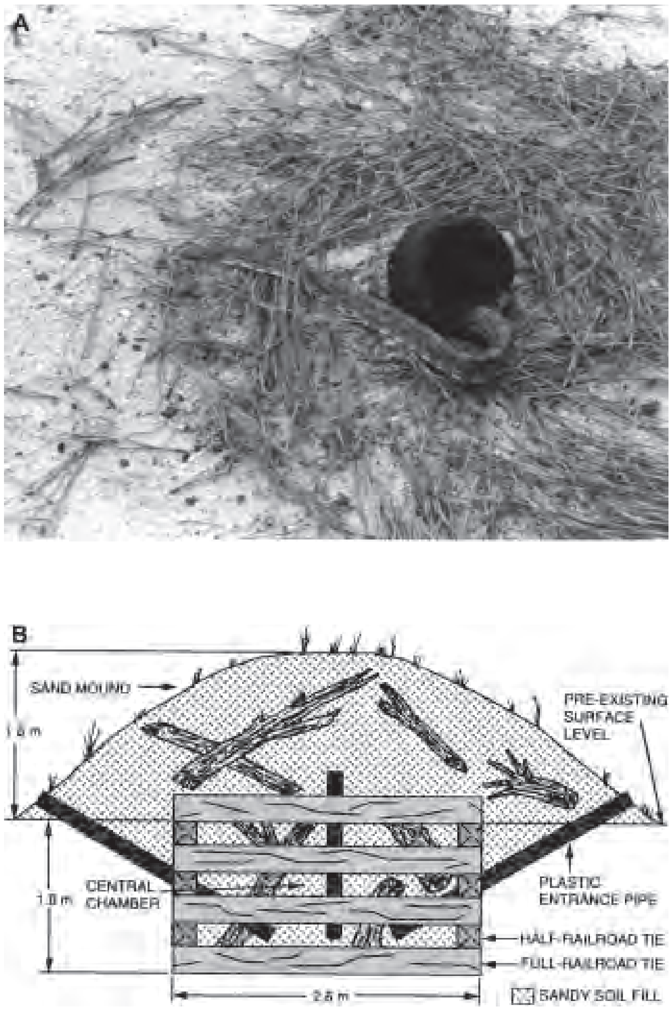


FIGURE 58 (A) Red Cornsnake (*Pantherophis guttatus*) going into the above-ground entrance to an artificial hibernaculum constructed as a conservation measure. This entrance is one of the terminal ends of the plastic entrance pipes shown in the diagram in (B) below. (B) Schematic drawing of an artificial hibernaculum constructed in a sandy substrate, so as to create multiple below-ground chambers accessible to snakes during winter. (From Zappalorti and Reinert 1994; © Society for the Study of Amphibians and Reptiles, reprinted with permission.)

den. The scanners must be placed at a natural or constructed "bottleneck" through which all individuals must pass. Because the presence of nearby metallic objects can interfere with the scanning process, any fence or housing constructed around the bottleneck should be made of wood. Automated PIT-tag systems can be programmed to record each PIT tag only once or multiple times at set intervals. Assumptions of this method are that every PIT tag is read, no PIT tag fails, and that no alternative entrances to the den exist. Automated PIT-tag systems were used successfully to record egress and ingress of approximately 350 rattlesnakes at a hibernaculum in an abandoned mine in New Mexico (A. Holycross, pers. comm.).

Lizards in hibernacula have been studied using radioactive markers (Grenot et al. 2000), but we do not recommend their use, because of potential detrimental effects such as tail loss. Fluorescent dye powder can be placed at a den entrance so that snakes move through it when entering or exiting the den. As an animal crosses the powder and crawls into the surrounding habitat, it leaves a trail that can be tracked with a field-portable ultraviolet light. However, the powder can be disrupted by wind and rain; it should be used only under optimal conditions, and the animals should be monitored frequently.

Artificial Dens

Artificial dens can be created to improve snake habitats where winter den sites are limited. Zappalorti and Reinert (1994) provided detailed plans for building a large artificial den from railroad ties, perforated PVC pipe, plastic sheeting, stumps, logs, and branches (Fig. 58). Nine species of snakes in the New Jersey Pine Barrens have occupied their artificial dens, which may be a useful conservation tool in some areas (Zappalorti and Reinert 1994). In South Carolina, artificial stump holes have been created to mitigate impacts of development, forestry practices, and stump removal on Eastern Diamondbacked Rattlesnakes (*Crotalus adamanteus*; H. Clamp, pers. comm.). Sewer junction boxes to which several 2- to 3-m-long, flexible, corrugated drainage pipes are attached are buried so that the top of the box lies approximately 1 m below the ground surface. The entrances of the pipes are only partially buried, to simulate stump-hole root channels. Research to determine the effectiveness of this latter type of artificial hibernaculum is needed.

Special Considerations

Several factors must be considered when planning surveys and monitoring programs for snake dens. Investigators designing or implementing visual surveys of known or new den sites must incorporate mechanisms to account for bias among observers with different search images, abilities to concentrate, experience, or knowledge of the target species (Rodda 1993). Observer biases should be studied to determine the effectiveness and characteristics of qualified biologists conducting visual studies at hibernacula.

Hibernacula are potentially limiting resources for many snake species (Parker and Brown 1973; Burger et al. 1988). Populations of many species have declined because of the loss of hibernacula to human development and/or the persecution of snakes at den sites (Klauber 1972; Parker and Brown 1973; Galligan and Dunson 1979; Gregory 1984a; Zappalorti and Reinert 1994). Locating hibernacula and monitoring communally denning populations of reptiles can provide information about many aspects of the target species' natural histories and can have important conservation implications. Exact locations of dens of sensitive, threatened, or endangered species should never be casually disclosed and should be reported only in conjunction with legitimate research and conservation efforts (Brown 1993).

Arboreal Reptiles: Tree-Trunk and Canopy-Dwelling Species

Indraneil Das

Sampling invertebrates from plants has been described as difficult, relative to sampling them from the ground or air, a generalization that is also true for sampling reptiles. Factors that impede effective sampling include the heterogeneous and continuous changing nature of plant-generated habitats (Southwood and Henderson 2000, p. 148), as well as their height. Indeed, arboreal habitats, which I define here as vegetation 2 m tall or taller (and, therefore effectively out of the reach of the average observer), are arguably the most difficult to sample. Rain forest trees can tower 30 m or more above the observer, with emergent trees in some areas reaching 50 m, and they have complex canopies (the upper levels of a forest). Many activities of arboreal species take place off the ground, on or in the forest canopy (where primary production takes place). Canopies are physically and biologically the most active part of the forest, and the architectural complexity of such habitats is attributed in part to the high faunal species richness in rain forests. Even when the canopy is accessible, collecting a reptile manually and inspecting the foliage with which it is associated are not always possible and depend considerably on the skills and experience of the collector. Consequently, comparing sample sets is difficult.

In recent years, estimates of the number of species inhabiting the earth have increased dramatically (May 1988, 1990; Stork 1993). Given that the estimates were extrapolated from counts of invertebrates, chiefly coleopterans, from the rainforest canopy (Erwin 1997), it is surprising that relatively little work has been done on canopy and other arboreal reptile communities. Sampling of amphibians from the mid-canopy of forests in the central highlands of Sri Lanka, for example, has recently led to quadrupling of the known fauna (Pethiyagoda and Manamendra-Arachchi 1998). Two groups of reptiles, lizards, and snakes, form a significant part of the arboreal reptile fauna. A single turtle, the Indo-Chinese *Platysternon megacephalum,* is reported to climb trees occasionally, possibly low tree trunks, to search for insects or to bask; I do not consider it here.

Arboreal reptiles may be visible to an observer as they expose themselves on trunks, branches, or surfaces of leaves, or they may be concealed under cover of leaves, flowers, or fruits; under loose bark; or in recesses of the trunk or branches. In the latter case, claw marks, smoothed entrance holes, or shed skin may betray their presence. Sampling protocols need to encompass the enormous variety of habitats and microhabitats used by arboreal reptiles. In general, our present knowledge of the ecology and systematics of many arboreal reptile groups is rudimentary. It would not be surprising to learn that some species categorized as rare or threatened are relatively common in the canopy. Indeed, groups typically thought to be terrestrial or even fossorial have been found in numbers in arboreal situations (Rossi and Feldner 1993; Das and Wallach 1998). Collections of canopy-inhabiting species tend to be fortuitous events, for example, when animals accidentally fall from their elevated perches or when trees are logged or fall during storms. In tropical areas, it is likely that many arboreal species of reptiles remain unknown to science.

Methodological constraints are a major impediment to the growth of our knowledge of arboreal herpetofaunas, for which effective survey methods are either difficult to design or expensive. Access to the high canopy, visibility, and access to the site itself are difficult or sometimes impossible without special equipment (Raxworthy 1988). In this account, I review the various techniques employed to sample reptiles occupying arboreal habitats, including scansorial species from trees and other tall vegetation.

Field Methods for Surveys

CLIMBING TREES

The choice of a tree to climb is important and often represents a trade-off. On one hand, old trees, clad with epiphytes, strangling figs, and rotting branches are centers of diversity for arboreal reptiles. On the other, such trees are often extremely difficult and even dangerous to climb. The potential risks of climbing trees, especially in the tropics, where biting and stinging insects and other invertebrates; snakes; plants with thorns, spines, and noxious secretions; rotting branches; and vertigo are common, can be significant. The sheer hardness of the wood in many species prevents nails from penetrating the trunk or limbs. In dipterocarp forests, lack of branches at levels below the canopy frequently makes free-climbing impossible.

When an appropriate tree is selected, developing a climbing plan is essential. Branches for support should be selected on the basis of their strengths, and positioning ropes across two branches, rather than one, enhances safety. The path upward must be scanned for all potential hazards enroute, including nests of biting or stinging arthropods and obstructing vegetation. Climbers sometimes wear head nets, gloves, and clothing made of heavy materials for protection when such pests are encountered. Regardless, free-climbing a tree is an extremely dangerous activity that, in most instances, precludes the transport of bulky field equipment or supplies. To enhance safety, individuals should be well trained in the use of climbing gear before attempting to scale a large tree, and all gear must be inspected for damage before every use.

LADDERS

Simple wooden ladders permit access to the canopy of short, stunted vegetation, such as that found in many montane forests and cloud forests (A. De Silva, pers. comm. 2000). The observer moves the ladders among various sites while trying not to disturb the population being sampled. From such elevated positions, the investigator can better detect the movement or reflected eyeshine of a reptile and collect it using one of the methods dealt with later (see "Blowguns and Shotguns" and "Laser Pointers," below). With careful examination, the surfaces of tree trunks, especially under peeling bark and within the often dense growths of epiphytes and bird's nest fern, sometimes yield a reptile, as do birds' nests and holes and cracks in a trunk or large limb, where unexpected reptile groups, such as dibamids and scolecophidians (generally considered to be terrestrial) may shelter.

CANOPY WALKWAYS

These structures, also known as catwalks and aerial walkways, have now been established on six continents. One walkway, built with 5-m-long sections of aluminum ladder, 13-mm diameter, 3,000-kg test-strength polyester rope, and perforated galvanized angle irons at Bukit Lanjan, Peninsular Malaysia, in the late 1960s lasted until 1976 (Muul and Lim 1970). The walkway was essentially a transect through the canopy, supported by several anchor trees. Two ropes were fixed between two trees and sections of ladders slid out on loops of rope suspended from the main cables. When in position, the loops were tied off, and each new floor section provided the base from which the next was set. Light boards were placed over the top. Rope or steel railings can be added for safety. Selection of the climbing point is important; the location of a tree on a slope can eliminate the need for a long climb up to the canopy (one enters the tree from the slope, well above its base) although this also eliminates vertical sampling (see "Tree Towers," below). Visual Encounter Surveys (VES; see "Visual Encounter Surveys," in Chapter 13) on canopy walkways are identical to those conducted on the ground or along waterways and are useful for compiling species lists of an area. Diurnal species are observed basking and/or foraging; nocturnal ones may forage openly under the cover of darkness and also may bask opportunistically to increase body temperature, synthesize Vitamin D, and carry out other physiological functions. On the forest floor, individuals of day-active species emerge from their hiding places as the forest warms; in rain forests, emergence often occurs around midday. Canopy species, given the more open nature of their habitats, may become active significantly earlier.

TREE TOWERS

A significant proportion of the reptile fauna of rain forests is found off the ground, and tree towers are appropriate for ecological observations and for specimen collection. Permanent towers of wood and metal now exist in several countries, primarily for botanical studies; others serve as fire-observation posts or for collecting meteorological data (described by Mitchell 1982). These structures offer potentially unparalleled opportunities for observations of a poorly known community of reptiles. Towers are sited on gentle topography, and on tall, healthy trees. Wooden platforms at various levels, up to the emergent layer of the canopy, permit long-term observations and sampling at different vertical strata of the forest. Sampling along tree towers addresses the vertical component of herpetological communities in tall forests. As with canopy walkway surveys, tree tower VESs of a vertical reptile fauna need to be conducted during the daytime and at night. The safety of the observers must be kept in mind at all times; the potential consequences of a fall from a poorly maintained canopy walkway or tree tower or through carelessness or accident are great.

CANOPY CRANES

Canopy cranes, established in many tropical and a few temperate forests, permit *in situ* studies of canopy life. A canopy crane consists of a free-standing construction crane, with a tower, operator's cabin, load and counterbalance jib, trolley, and hook. A suspended personnel basket (gondola) is attached to the hook to carry personnel up into the canopy. At the Smithsonian Tropical Research Institute in Panama, two construction cranes allow access to the upper forest canopy and other inaccessible reaches of a rain forest, permitting observation. The observers, up to four at a time, in addition to heavy equipment, are lifted in small gondolas and lowered at desired levels within the canopy. The crane operator is in contact with the observers via two-way radio. At the Wild River Canopy Crane Research Facility, in Washington State, it is possible to access the canopy at 87 m, using gondolas that carry up to eight persons or four persons and equipment, to a maximum load of 2,286 kg. A three-dimensional system for maneuvering the gondola through the canopy is used. Attention to local weather conditions is important, and thunderstorms and icy conditions increase risks to the observer.

CANOPY RAFTS

Gigantic rafts of helium balloons ("canopy bubbles") have been placed over canopy sites in French Guyana, Cameroon, Gabon, and Madagascar to provide access to the roof of the forest (see Hoogmoed and Avila-Pires 1990, 1991; Reagan 1995). The canopy raft (also called "radeau des cimes") consists of air-inflated beams with Aramide netting between them, which are connected by ropes and set up by a team of specialized climbers. The rafts permit observers to work and live for a few days at a time in the canopy. Air-inflatable dirigibles launched close to the raft from a launch pad covered with a plastic tarpaulin (to provide cushion) allow observers to ascend to the canopy via a single-rope technique (described by Hallé and Blanc 1990). One canopy raft established in 2001 in Masoala National Park, Madagascar, serves as an access platform permitting researchers to inventory interior valleys as well as the canopy itself. The canopy bubbles, each with a 500 m^2 platform and linked by ropes, form a network that covers ca. 2 km^2, in an area ranging from sea level to ca. 400 m ASL. The high cost of establishing a canopy raft (French Francs 6 million for the one in Madagascar in 2001) has prevented the establishment of raft networks for canopy sampling in other tropical sites.

Methods for Collecting Specimens

BLOWGUNS AND SHOTGUNS

Blowguns, typically hollow wooden implements that deliver an often poison-tipped dart, have been utilized by traditional hunter-gatherer societies throughout the world. The use of blowguns can substantially increase the number of specimens of highly arboreal but seldom-collected species of lizards such as *Draco* available for study (e.g., Inger 1983). Modern, aluminum blowguns are commercially available from hunting or sporting goods shops; these devices fire a molded plastic, stun-plug pellet or a .4-calibre metal dart, also available commercially (see also "Sling Shots and Blowguns" in Chapter 5). The range, depending on the skill of the collector, can be up to 8 m. Success is greater when shots are taken horizontally, such as from an elevated site (e.g., a ridge top or canopy walkway), rather than vertically, as from the base of a tree and up along the trunk. In general, shots need to be aimed at the body to avoid damage to the head. For studies that require examination of the reproductive tracts or diet, a head shot may be preferable. Using balls of plasticine or modeling clay as projectiles can minimize damage to specimens of delicate species; other, more robust lizards (such as large skinks, with hard osteoderms in their scales, or large agamids) are often immobilized by barbless metal-tipped darts (with plastic bases). The mortality of lizards (especially scincids) collected with stun plugs and darts is relatively low.

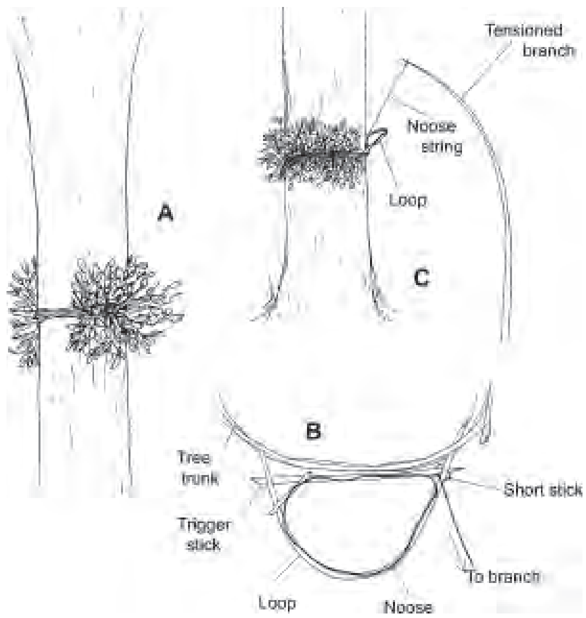


FIGURE 59 Mangmaty trap for noosing large arboreal lizards. (A) Target tree, with barrier. (B) Trigger mechanism (see detailed description under "Nooses and Baits"). (C) Tree with trap, showing angle of loop. (From Bennett et al. 2001; © Society for the Study of Amphibians and Reptiles, reprinted with permission.)

Many diurnal, arboreal lizards can also be shot with air pistols or BB guns (see "Firearms" in Chapter 5), although mortality is higher than with blowguns (Vitt and de Carvalho 1992). As with blowguns, shots can be taken at the head region to avoid damage to the internal organs. Specimens obtained may need to be preserved promptly or stored in a box of ice or similar cool chamber. The use of guns is restricted in many countries, and it is essential that investigators consult local authorities about regulations regarding their use and obtain necessary permits before using them. Regardless of collection method used, recovery of specimens shot far from the forest floor, such as from a watch tower or canopy walkway, can be difficult.

NOOSES AND BAITS

Certain large-headed lizards that permit close approach by observers (such as small varanids and iguanians) can be captured with a noose of fishing line or waxed dental floss (see "Noosing," in Chapter 5). The device can be attached to either a stout stick (in the case of a large quarry, such as a small varanid) or a telescopic (which facilitates transport) fly-fishing rod. With mealworms or similar commercially available invertebrates, fly-fishing rods can also be baited for capturing small insectivorous lizards. To reduce stress from noosing, animals to be released should be freed as soon as possible. Bennett et al. (2001) described the use of the *Mangmaty trap* (Fig. 59) for noosing large arboreal lizards (such as varanids). Materials required to make the trap, which is based on a traditional trigger-sprung trap widely used in the Philippines, include a rope or vine, 150 cm of parachute cord with a running noose tied at one end; a 30 × 16-cm loop (diameter appropriate to accommodate the lizard) made of flexible branches or vines; and two wooden sticks 5 cm in diameter, one 30 cm long (trigger stick) and the other 4 cm long (short stick). The investigator selects an appropriate tree and ties the rope or vine around the trunk, to which a wall of vegetation is attached to block off all but a 30-cm narrow path on the trunk on the side of an upward slope. The passage of the lizard through the loop puts pressure on the trigger stick, causing the small rod to detach, tightening the noose.

A second method of snaring varanids was described by Reed et al. (2000). A baited trap of wire mesh (e.g., chicken wire), to which multiple-monofilament snares are tied in a grid, is attached to a tree trunk (see Fig. 64). Hooks are tied to the wire mesh and baited with an appropriate live prey or other food. When a lizard crosses the trap, one or more of its limbs catch in the snares and pull them tight. The trap is inexpensive and easy to transport, and mortality is insignificant. Nooses and baited fishing rods can be used both from the ground, to catch lizards active low on tree trunks, as well as from tree towers and canopy walkways to capture the more arboreal species.

ADHESIVE TRAPPING

Sticky traps are an efficient method for catching reptiles, such as snakes, iguanians, scincids, and gekkonids, that move vertically along a tree trunk (Bauer and Sadlier 1992; Rodda et al. 1993). The traps are made by spreading commercially available mouse-trapping glue on hard boards, which are then attached to a tree trunk or branch. Trap placement is an important determinant of trap success; traps should be placed near basking sites, along trails, or close to observed retreats. Sticky traps can be sited in naturally shaded areas or in sunny ones (e.g., basking sites). Mortality of specimens trapped in the latter microhabitats is greater due to dehydration and, potentially, increased predation. Investigators can release captured animals by applying a few drops of vegetable (e.g., canola) oil with a paint brush. Special care needs to be taken when detaching individuals of soft-skinned species, such as gekkonids or species with tail autotomy, such as scincids. To increase capture efficiency, glue traps can be baited. Whiting (1998) used figs painted red for frugivorous cordylid lizards. For additional information on this type of trap, see "Adhesive Traps" in Chapter 5.

Unfortunately, mortality (resulting from stress, injury, and predation) is relatively high with sticky traps, as is the capture of nontarget organisms, both of which raise ethical issues. Adhesive trapping may be inappropriate for use with threatened species or for long-term field studies. Depending on the substrate used, weather conditions, and exposure, glue traps can remain effective for from 2 to 5 days. However, capture rates decrease with time, due both to depletion of vulnerable animals and deterioration of the trap (Rodda et al. 1993), and the traps are difficult to attach to the small branches and leaves that are frequented by certain species.

LASER POINTERS

Commercial laser pointers, available at office supply stores, are used in all kinds of lectures and presentations to draw attention to particular points on slides. Beams from laser pointers attract certain nocturnal, arboreal reptiles such as gekkonid lizards to the projected light, which possibly is mistaken for food or perhaps a potential competitor. From their usually high perches, gekkonid lizards can be lured toward a pre-sited assistant or a trap. This technique works well on walls of buildings as well as tree trunks, and it is more successful in the early evening than later, presumably when geckos are becoming active and are hungry.

The diode generates a narrow beam, ca. 1 mm in diameter that becomes increasingly enlarged and diffuse with distance. Some laser pointers have adjustable focusing systems, and depending on the wavelength used, 670, 650, or 635 nm (red pointer), the range in total darkness can be 300 m, 600 m, or 1,220 m, respectively. Beams from a green laser (wavelength 532 nm) have a greater capacity to hurt the retina of the human eye than the red lasers. Pointers run on 3V DC import power, most conveniently supplied by AAA or two to four LR 44 batteries (watch batteries). The energy a pointer emits is several times greater than that received by the eye when staring directly at the sun. Consequently, care must be taken not to inadvertently point the beam directly at the eyes of colleagues or study subjects. Laser beams can damage the retina, leading, in extreme cases, to loss of vision. The sale and use of certain classes of laser pointers are banned in some countries.

DRIFT FENCES

Drift fences, in conjunction with pitfall traps, have been long used to trap surface-dwelling species of reptiles and other fauna (Campbell and Christman 1982; Dodd 1991; see "Funnel Traps, Pitfall Traps, and Drift Fences," in Chapter 5, and "Pitfall-Trap Surveys," in Chapter 13). Vogt (1987) modified the system to trap arboreal salamanders. In principle, a drift fence is an upright surface that directs wandering reptiles (or other species) into the open mouth of a trap (usually a pitfall trap). In arboreal situations, it is often a plank that directs tree-dwelling lizards into a funnel trap. Drift fences can be constructed of any hard, smooth-sided object, including hard plastic sheets, hardware cloth, netting, metal sheets, or window screen. Traps need to be checked periodically to prevent trapped animals from starving, desiccating, or being eaten.

BAITED AND UNBAITED TRAPS

Depending on the activity and behavior of the target species, specific traps can be installed to capture arboreal reptiles. Minnow traps, which are easily manufactured (instructions are available on various websites) as well as available commercially in various sizes and materials, are especially effective. The trap consists of a cylinder with a funnel extending inward at one or both ends or on one side. Zani and Vitt (1995) used commercial minnow traps in Ecuador to capture tropidurid lizards that use tree holes as refugia. They chased lizards into a tree hole, plugging all other holes with cloth, and then placed the entrance of their minnow trap over the hole. They tied the trap securely to the branch with nylon string. Lizards emerging from the hole (the only one available) entered the minnow trap, whose entrance had been modified to accommodate the head dimensions of the largest males in the target group. Rodda, Fritts, Clark et al. (1999) also used minnow traps to capture *Boiga irregularis,* a snake pest, for the purpose of control. Capture rates were enhanced through the use of mouse baits. Rodda and Nishimura (1999) reviewed the effectiveness of a variety of trap types. Several traps were designed to discourage retreat of entering snakes, including "metal whisker" traps (in which the mesh screen around the entrance hole is frayed), "split-cone" traps (in which the plastic around each entrance hole is slit radially many times [>12]), and "flexible squeeze" traps (in which the entrances are comprised of folds of window screening or other mesh pieces that meet along a linear midline). Traps may be baited with an appropriate live prey or other food or left unbaited. Most traps used to sample arboreal reptile populations work for snakes and large lizards (such as varanids). Traps, however, are prey specific, and not all arboreal reptiles can be trapped.

CANOPY FOGGING

Arboreal invertebrates are widely sampled by fogging the canopy of a tree with biodegradable pesticides of the pyrethrin group, which cause enhanced activity, leading invertebrates to fall off the tree (Southwood and Henderson 2000, p. 156). Pyrethrins have no long-term effects on development or reproduction in invertebrates (Paarmann and Kerck 1997), but their effect in reptiles remains unknown. The arthropods are collected from a plastic sheet placed under the tree either on the ground or on a raised metal frame with short legs. In rain forests, a mist-blower or fogger that has been hoisted into the canopy using a rope and pulley system produces a fine spray of insecticides that drifts and penetrates the canopy. The release of the insecticide is controlled from the ground by a radio transmitter that operates a servo unit on the fogger, opening and closing the insecticide-release valve (see Stork and Hammond 1997). In the Danum Valley, Sabah, in northern Borneo, where extensive canopy-fogging studies have been carried out, arboreal skinks belonging to two genera (*Sphenomorphus* and *Lipinia*) have been taken as incidental catch (ID, unpubl. data). Reptile species that can evade the chemicals by retreating into sheltered locations, such as cracks and holes within the trunk or branches, are not represented in the samples. Limitations of fogging include its dependence on calm weather (such as at daybreak) and the lack of information on the effects on reptiles of the chemicals typically used (specific for arthropods). Additional studies of canopy fogging as a method for sampling arboreal reptiles are needed. Development of site-specific methods for sampling the canopy herpetofauna should be a priority, and canopy-fogging protocols for collecting invertebrates in tropical rain forests should incorporate techniques for sampling arboreal reptiles.

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Swamp-Dwelling Crocodilians

William E. Magnusson

Swamps are ubiquitous but hard-to-define habitats. Open marshes, floating grass mats over lakes, flooded shrublands, and mangrove forests are all considered swamps. In general, if it is wet and hard to survey, it is a swamp. Swamps border most rivers and lakes, and most swamps have rivers or lakes that drain them. Therefore, most species of crocodilian inhabit swamps to some extent.

The swamp obviously becomes a problem to the surveyor when the target species is inaccessible because of difficulties of moving through thick vegetation. However, swamps are often the homes of nesting female crocodilians (Joanen and McNease 1987), which are demographically the most important segment of the population, even though most males and juveniles may live in other habitats. Estuarine Crocodiles, *Crocodylus porosus,* including adult females, spend most of their lives in estuarine habitats. However, in many areas, the only available nesting sites are found in small freshwater swamps (Magnusson et al. 1980). Density may be a misleading indication of wildlife habitat quality (Van Horne 1983). This is especially important for crocodilians because individuals excluded from preferred areas by the territorial behavior of dominants may congregate in suboptimal habitats (Messel, Vorlicek, Wells, and Green 1981).

Surveys in Adjacent Habitats

Investigators have rarely surveyed flooded forests because trees cannot persist in areas that are permanently flooded. It is usually easier to carry out surveys when tidal or seasonal decreases in water levels concentrate crocodilians in smaller areas of open water where they can be detected by spotlight surveys (see "Finding Crocodilians," under "Finding, Counting, and Catching Crocodiles," in Chapter 5). The assumption that all individuals leave previously flooded forest at low water has not been tested for most species. *Osteolaemus tetraspis* appear to remain in terrestrial burrows at low water (Riley and Huchzermeyer 1999), and *Paleosuchus trigonatus,* while not strictly a swamp species, spend much of their time in burrows in areas of forest that do not flood (Magnusson and Lima 1991). Surveys for these species require a lot of walking, as well as knowledge of the behavior of the species that can be obtained only with radio telemetry.

As with any survey, the appropriate sampling method depends on the data that are needed (Webb and Smith 1987). However, interpretation of the results is unlikely to be possible unless based on accurate maps of the swamps and other aquatic habitats surveyed. Therefore, considerable effort should be devoted to analysis of aerial photographs and satellite images of those areas. Evidence of crocodilians around a swamp is good evidence that crocodilians use the swamp. Therefore, spotlight counting in surrounding open water may be useful in broad-scale surveys to determine the presence or absence of crocodilians in the region. If a large sample of the observed crocodilians can be captured, analyses of the population size structure and sex ratio will provide some indication of the role of a swamp in the population dynamics of the species. If mainly adult males and juveniles are captured, the swamp is probably functioning as a source and the open water areas as a sink for the population.

Even if the surrounding areas contain a balanced sex ratio, the swamp may be important as a refuge from hunters. Considerable evidence in the wildlife and fisheries literature indicates that management is more likely to be successful when hunter access to a source population is reduced (e.g., Allison et al. 1998; Novaro et al. 1999). Swamp crocodilians may also be more resistant to hunting because of a decreased frequency of social interactions with larger individuals of the same species

(Magnusson 1986). More detailed analysis of the importance of swamps to population dynamics of crocodilians will require information from within the swamps, and the time and money required for surveys will escalate.

Mark-Resight Techniques

Relatively open swamps can often be surveyed by boat or aircraft. Bayliss (1987) marked crocodiles (*Crocodylus porosus*) with plastic cattle tags attached to detachable barbed metal shafts that were driven into the neck skin with a harpoon pole. He then employed mark-resight techniques to estimate the population size in several habitats in northern Australia. The proportion of marked animals resighted was relatively low in mangrove-lined creeks. Bayliss (1987) also carried out daytime helicopter surveys of mangrove habitat in areas where crocodile densities had been estimated previously by mark-resight techniques. He found that the helicopter surveys detected only a small proportion of the population known to be present in mangrove-lined creeks. Mourão, Bayliss et al. (1994) marked Yacare Caimans (*Caiman yacare*) in vegetation-covered lakes of the Pantanal with white paint and resighted them from an ultralight aircraft. They determined that only about 2 percent of the caimans in the lakes were visible from the air. Mark-resight techniques are too expensive to apply on a large scale and are used mainly to calibrate other techniques for use in similar habitats.

Radiotelemetry

Radiotelemetry studies may aid in the interpretation of results of spotlight and other surveys of small swamps. If an investigator can capture a reasonable sample (e.g., >10 individuals) of each demographic segment (adult males, adult females, and juveniles) in the swamp and attach a transmitter to each individual, then she or he can use subsequent locations of the animals taken from the radio signals to estimate the proportion of time each group spends outside the swamp (e.g., Joanen and McNease 1970). Such information provides a basis for calibration of spotlight counts in aquatic habitats adjacent to the swamp. Radiotelemetry is probably the only secure means of determining habitat partitioning among size and sex classes. Radio telemetry also may indicate the proportion of time that forest animals spend in burrows away from streams (Magnusson and Lima 1991). The easiest way to attach radio transmitters to crocodilians is to sew them onto the tail scutes (Muñoz and Thorbjarnarson 2000; Campos et al. 2006); unfortunately, the exposed radios can catch on the thick vegetation in swamps, pulling out the sutures and causing the radio to detach from the animal. An alternative is to implant radios in the abdominal cavity (Magnusson and Lima 1991; Campos et al. 2006). This is more time consuming and stressful for the animal but has the added advantage that data can be obtained on body temperatures (Campos et al. 2005).

Hand capture of crocodilians in swamps is difficult. However, various types of traps used in open water (e.g., Hutton et al. 1987; Walsh 1987; Mazzotti and Brandt 1988) also work in swamps. Small (total length <1 m) crocodilians are easily captured in baited turtle traps, but larger individuals may tangle their teeth in the bottom of the trap and drown. The time and costs associated with capturing crocodilians in swamps is usually worthwhile only if the individuals will be equipped with radios and monitored intensively.

Diurnal and Nocturnal Surveys

Spotlight surveys from open water are rarely useful in swamps because the light penetrates only a short distance into thick vegetation and most animals are likely to be missed. At the same time, surveys on foot are usually too laborious to be effective over large areas. Airboats and marsh buggies, which can travel over thick reeds and provide access to the center of open marshes, have been used in many studies of American Alligators, *Alligator mississippiensis* (e.g., Joanen 1969; Joanen and McNease 1979). However, these vehicles destroy vegetation and wildlife, and their use in most parks and reserves is now prohibited or severely restricted. Airboats and marsh buggies would be especially appropriate for seasonally flooded swamps, such as the Pantanal and the Llanos, where the periods of high water are too short for the production of luxuriant aquatic vegetation. Nonetheless, their high costs and maintenance requirements have so far restricted their use outside of North America. Nocturnal helicopter surveys may provide accurate counts in some swamps (Graham 1977), but the high cost and low safety margin of helicopters preclude their use in most situations.

Mourão et al. (2000) carried out daytime aerial surveys of caimans from small planes in the seasonally flooded swamps of the Brazilian Pantanal. They were able to count individuals easily only when low water levels caused them to concentrate in open areas. Most of the variation in numbers of individuals observed was related to the level of flooding and, therefore, the degree of animal dispersion and amount of aquatic vegetation lining residual waterbodies at the time of the survey. Similar problems have been reported for ground surveys of caimans (Campos et al. 1994) and boat surveys of alligators (Woodward and Marion 1979), caimans (Da Silveira et al. 2008), and crocodiles (Montague 1983; Jenkins and Forbes 1985; Cherkiss et al. 2006) in swamps and wetlands.

Artifacts as Indices

In the absence of direct counts of individuals, artifacts may be used as indices of population size. Riley and Huchzermeyer (1999) concluded that pools and burrows indicated the presence of *Osteolaemus tetraspis* and guessed the number of individuals in burrows to estimate population sizes. Track surveys on mud banks in mangrove forests can also be used as indices of population size or to determine the size structure of segments of the population (e.g., Wilkinson and Rice 1996). However, nests are the artifacts most widely used to monitor crocodilians in swamps.

All crocodilians that nest in swamps make large, long-lasting mound nests (Greer 1970) that can often be detected from ultralight aircraft (e.g., Campos 1993), helicopters (e.g., Webb, Whitehead, and Manolis 1987; Campos and Mourão 1995), or fixed-wing aircraft (e.g., Magnusson et al. 1980). The number of nests detected can be used directly as an index of the number of breeding females (e.g., Hollands 1987); alternatively, counts of nests detected by independent observers can be manipulated statistically to estimate the total number of nests present (e.g., Magnusson et al. 1978; Mourão, Campos, and Coutinho 1994; Mourão and Magnusson 1997). Regular monitoring will reveal any extreme drop in nest density that could indicate a reduction in population size.

Chabreck (1966) presented a formula for estimating the number of American Alligators in an area based on the average number of nests counted. However, nest densities usually fluctuate widely among years, depending on climatic and other environmental factors (e.g., Hayes-Odum and Jones 1993; Campos and Magnusson 1995), so short-term monitoring is usually of limited value, and it is extremely difficult to relate nest numbers to numbers of breeding females or total population size. The State of Florida conducted one of the most detailed (and expensive) population studies of any crocodilian species on American Alligators in Orange Lake (Hines and Abercrombie 1987). Based on the study results, the Florida Game and Freshwater Fish Commission subsequently allowed hunters to take a large proportion of the adult females estimated to be in the lake. After 4 years of hunting, no effect on the number of females nesting around the lake was apparent, a result that was not biologically feasible if the original density estimates were correct (Hines and Abercrombie 1987). Attempts to estimate the absolute densities of crocodilians in swamps are, as in other habitats, unlikely to be cost effective. Careful monitoring of relative densities is much more likely to be of value for adaptive management (Bayliss 1987).

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Detecting and Capturing Turtles in Freshwater Habitats

Richard C. Vogt

On Land

BY HAND

The most primitive methods of capturing both freshwater and terrestrial turtles is by hand after stumbling upon them in the leaf litter of the forest understory (e.g., *Terrapene carolina, Kinosternon leucostomum, Geochelone* spp.) or encountering them as they cross a road. Many aquatic and terrestrial species cross roads during migrations to nesting or hibernation sites, during spring or post-hatching dispersal, or after departure from drying ponds. Road-killed turtles can document valuable locality data as well as estimates of population size based on the quantity of road kills. Researchers studying terrestrial turtles often walk systematically through favorable habitats looking for turtles or their sign.

SIGN

Sign includes scats, tracks, burrows, partially eaten vegetation (*Opuntia* fruits, leaves with bite marks), fresh nests (or ones that have been preyed on), and turtle trails. With an intimate knowledge of turtle ecology and behavior as well as a good search image, investigators can look for the correct type of sign in the most appropriate places for the season and weather conditions. Legler (1960b) systematically searched for Ornate Box Turtles (*Terrapene ornata*) under shrubs and mulberry trees, along trails, and along unplanned drift fences (e.g., stone fences in Kansas), as well as looking for cattle dung that they had torn apart to locate the contained dung beetles. He also systematically rode through these areas on horseback because it was easier to see the turtles from higher up and because the turtles were accustomed to horses and did not spook as easily as they did in response to humans.

TRAPS AND TOOLS

Researchers have captured *Gopherus* tortoises around active burrows using hooks (Woodbury and Hardy 1948), small-mammal live traps, pitfall traps at burrow entrances, and drift fences with pitfall traps or funnel traps (Plummer 1979). They also may dig an individual from a burrow. More-creative methods of turtle capture include (1) releasing a male tortoise into a burrow (if a resident male is present he will usually come charging out after the other male), and (2) installing a Plexiglas door at the burrow entrance that permits the tortoise to exit but not reenter. Indigenous people of the Amazon rain forest collect *Geochelone* spp. in large pitfall traps. They kill a large mammal such as a paca and hang it above a 1- to 2-m-deep straight-sided hole. As the carcass putrefies, the odor attracts tortoises (and other animals) of all sizes from the surrounding area; while searching for the carcass, they fall into the hole. The pits are checked after a few weeks.

DOGS

The most efficient way to collect terrestrial turtles of any kind in any habitat is with trained dogs, whose olfactory senses far exceed those of their handlers. More than 90 percent of 3,832 box turtles collected by Schwartz and Schwartz (1974) were found by their Labrador retrievers. A dog trained by commercial turtle hunters helped us to find *Kinosternon leucostomum* when they were estivating in the forest (Morales-Verdeja and Vogt 1997). The dog looked for turtles in the leaf litter, under boulders and fallen trees, and under water. Breeds of dogs that are best for turtle hunting have a keen sense of smell, are close to the ground, and have been trained from a young age to hunt turtles; generalized hunting dogs are easily distracted by the scent of other game (D. Moskovits, pers. comm.).

DRIFT FENCES

Drift fences, often combined with pitfall traps and funnel traps (see "Funnel Traps, Pitfall Traps, and Drift Fences," in Chapter 5), are effective for sampling populations of terrestrial turtles as well as freshwater turtles migrating on land to or from nesting grounds or leaving a drying pond. Drift fences work only when the animals are moving, so collectors must have some knowledge of the turtles' activity patterns. Sexton (1959a) increased his success at collecting *Chrysemys picta* by blocking the migration route to its nesting ground with 25-cm-tall, 100-m-long barriers and slowing the turtles to his pace. Gibbons (1970) modified this technique by completely encircling ponds at the Savannah River Site (SRS, Department of Energy, South Carolina) with drift fences with pitfall traps; he managed to collect nearly all of the turtles from the ponds during their nesting or other terrestrial migrations. He used the system to catch previously captured turtles as well as newly recruited hatchlings on their return to the pond.

Drift fences must be monitored on a regular basis depending on the number of turtles moving through the area and the density of predators. Mike Pappas (pers. comm.) had so many *Emydoidea* moving along his drift fences that if the traps were not checked every few hours during peak nesting periods the buckets would fill with turtles. Predators, such as raccoons (*Procyon lotor*), also learn about drift fences and will walk along them to harvest hatchling turtles in the pitfall traps. For this reason, at least during the hatchling migration season, buckets should be fitted with screen, plastic, or metal funnels that allow hatchlings to pass through into the bucket but prevent raccoons or other predators from gaining access (Vogt and Hine 1982).

Drift fence designs for sampling squamates are discussed elsewhere (see "Pitfall-Trap Surveys," in Chapter 13). Adding turtle traps increases trapping efficiency. The best material to use for fences depends on several factors: efficiency at capturing the target species, ease of installation and maintenance, permanence, and cost. The complete-enclosure fence and buckets arrangement that Gibbons (1970) used at the Savannah River Ecology Laboratory (SREL, University of Georgia, at SRS) is a relatively maintenance-free system that lasts for decades. However, the aluminum flashing or galvanized sheet metal that he used for the drift fences is cost prohibitive for some studies, too heavy to carry into distant areas, attractive to thieves in well-populated areas (for house repairs or selling for scrap metal), and so forth. In public-access areas, aluminum flashing may even attract vandals (RCV, pers. observ.). Thick industrial plastic tarp material can be used for the drift fences instead of metal; it is inexpensive, easy to carry, and has little resale value, making it unattractive to vandals. When not in use, the plastic can be dropped to the ground, rolled, hidden (covered with leaves, sand, soil, snow, or other natural material), and employed again when desired. On the other hand, plastic has high maintenance requirements. Holes and tears caused by animals passing through the fence, falling branches, wind, and so forth have to be repaired regularly, and fences must be raised upright after being flattened by heavy rains, hail storms, or branches, or even replaced after being destroyed by one of those factors. Also, the replacement interval for plastic is much shorter than that for metal materials, which can remain in place for years, even in the tropics. Plastic or aluminum window screening can be used, but both cost more than plastic tarp material and are more difficult to hide when a fence is lowered to the ground. Researchers who work in secure areas and have the funds should use metal drift fences. Thirty meters (at least) of drift fences with pitfalls can be setup in sections to transect the overland migration routes of aquatic turtles from the water to nesting sites. In general, arrays of drift fences with pitfall traps designed for catching reptiles and amphibians are useful for recording the presence of some terrestrial turtles (e.g., *Terrapene*) in the habitat being sampled, although I am unaware of any long-term studies in which drift fences have been used for continual capture of these animals (Vogt and Hine 1982).

In Freshwater

HAND CAPTURE

Basking aquatic turtles can often be captured by hand or dipnet if approached underwater or from the rear. Investigators traveling by boat can rush basking turtles at full speed and often pluck them off a log or sweep them into a dipnet. The late Fred Cagle, a herpetologist from Tulane University, was notorious for using this technique day and night to collect *Graptemys,* which often sleep underwater on submerged branches in clear-water habitats (Cagle and Chaney 1950; J. L. Dobie, pers. comm.). Nevertheless, the technique is inappropriate for systematic sampling. In the rivers of southern Mexico, my students and I saw *Dermatemys* swimming underwater in clear-water streams, but they were too fast to catch if one was snorkeling. We were, however, able to capture them by diving off a moving boat. We used this technique day and night with a spotlight. J. M. Legler (pers. comm.) also caught most of the turtles in his Australian studies by diving for them. I have also approached *Graptemys ouachitensis* while they were surface feeding in the Mississippi River backwaters. When they submerged their heads to feed, I moved forward rapidly; when they emerged to look around, I froze. My head was camouflaged with a mat of aquatic vegetation, and only my eyes were above water. Because it takes 20 to 30 min to catch a turtle, this technique it is not very efficient.

Muddling, or *noodling* (see "Blind Capture," under "Alternative Methods for Sampling Aquatic Turtles and Squamates," below), for turtles in shallow water involves feeling for them in the mud, the nooks and crannies below logs, snags, rocks, and under overhanging banks with your hands. Such haphazard methods of capturing turtles suffice for locality documentation but are generally inappropriate for quantitative sampling. Investigators working in a closed system, such as a small pond, can perhaps capture all of the turtles present by muddling. In the Brazilian Amazon I have caught more than 40 *Podocnemis unifilis* within 2 hours in small backwater ponds during the dry season. M. A. Ewert (pers. comm.) collected thousands of turtles this way throughout the United States. Kinosternids are particularly easy to catch in this manner. An extension of muddling is *sounding*, or *poling*, in which the collector abruptly drops a wooden pole into the mud in springs or in areas of water where bubbles are surfacing. If the collector hears a hollow plunk, she or he, reaches underwater to grasp the turtle. Professional turtle trappers in Wisconsin effectively diminished populations of *Chelydra* and *Glyptemys insculpta* congregated in winter hibernation using this technique. Usually there is a hook at one end of the pole that is used to pull the turtle from the water. This technique has also been used in Mexico during the dry season to find *Staurotypus*. In the Brazilian Amazon, the hook is replaced with a spear point. The spear head, a rectangular point of steel, is quite small (2 × 3 mm) and is tied to the pole by a string. When the spear head strikes a turtle, it is released from the pole and impales the turtle carapace, functioning much like a harpoon. The investigator uses the string to haul in the point and turtle. This method is best suited for documenting a species' occurrence. Poling for turtles requires some basic training and a feeling for where turtles can be found.

Collectors in Mexico use a similar technique for terrestrial turtles, particularly *Kinosternon acutum* and *Rhinoclemmys areolata*. A blunt 2-penny nail is driven into a 25-mm-diameter wooden pole that is thrust horizontally through the leaf litter at the base of shrub clumps. When the nail hits a turtle, it makes a plunking sound, different from that made when hitting a rock or tree branch. We located several dozen turtles on a regular basis when using this technique. The technique is especially valuable for locating turtles during the dry season, when they do not move around. Carpenter (1955) used a similar technique to locate five species of turtles, including hibernating individuals.

BASKING TRAPS

Traps designed to capture basking individuals are effective in temperate climates for the many species of turtles that bask frequently. The simplest design is to attach plastic or metal baskets to the basking logs (Carr 1952). A collector surveys the area to be sampled with binoculars or a spotting scope to locate the preferred basking sites. He or she then attaches baskets to one side of the log below areas where turtles are accustomed to returning to the water. The lips of the baskets should be flush with the water surface so that the turtles can escape when the baskets are not attended. The collector rushes the basking log from the side opposite the baskets, the startled turtles fall into them, and the collector rapidly removes the turtles before they climb out. Brian Horne (pers. comm.) used this technique successfully when studying *Graptemys flavimaculata* on the Pascagoula River in southern Mississippi. This technique allows for dietary studies because fresh stomach contents can be collected from turtles that have not consumed trap bait (e.g., see Legler 1977; Fields et al. 2000). Also, because the turtles have not been stressed by trap confinement, blood can be analyzed for circulating hormone levels without fear of biased results caused by stress. The drawbacks of the technique are that it only works with species that bask, is time consuming, requires ideal basking sites, and in most species, apparently, is biased toward females and juveniles.

Floating basking traps consist of a square or rectangular wooden frame with a wire mesh or nylon bag attached beneath the center. Planks are angled like seesaws, from the surface of the water, over one side of the frame (which serves as a fulcrum), and toward the center of the trap; the turtles come out of the water to bask and climb higher and higher on the wooden planks until they reach the other side of the fulcrum and are dumped into the trap basket, from which they cannot escape. The seesaw plank reverts to its position in the water after the turtle slides off. Although these traps are good for long-term population studies, they are not adequate for routine sampling, because the turtles must become accustomed to the newly offered basking areas, the traps are bulky to carry around, and many turtle species do not bask.

Another active basking trap is a modification of the bal-chatri trap used to capture birds of prey and wading birds (Foster and Fitzgerald 1982). Hundreds of snares (slip nooses) made of monofilament fishing line are tied to pieces of galvanized chicken wire 0.5 m on a side (Fig. 64). The wire is then molded to fit onto any basking surface and nailed or tied to it, or it can be placed on sand beaches. As the turtle walks over the trap, its arms or legs get caught in the nooses, which close as the animal struggles. As with any basking trap, the investigator must know where the turtles are basking. After the trap is in place, it must be checked every few hours to keep the turtle from drowning, excess sun exposure, or being taken by birds of prey (Braid 1974). Various more complicated basking traps with multiple treadles have been invented; they are described in Lagler (1943), Breckenridge (1944, 1955), Ream and Ream (1966), Robinson and Murphy (1975), and Plummer (1979).

BASKING SURVEYS

Basking surveys can also be conducted using high-powered binoculars or spotting scopes. Obviously these types of surveys are only appropriate for species that bask at certain times of day and seasons. C. J. McCoy and I (pers. observ.) used this technique most effectively for assessing population densities of *Graptemys flavimaculata, G. nigrinoda,* and *G. oculifera*. Our data were substantiated by simultaneous trapping with Fyke nets (extensions that extend out from hoop traps that function like drift fences; see description under "Baited Hoop Nets," below). We floated downstream in a boat or canoe, one person in the stern steering and the other in the bow with a 30X spotting scope. To standardize our results we floated rivers on sunny days for 2-h periods between 09:00 and 11:00, when turtles would most likely be basking. We were able to identify and determine the sex of adults of eight species of turtles as well as identify hatchlings to species. We also identified but did not determine the sex of two additional species. Lindeman (1997) also used this technique for censusing *Graptemys* populations in Tennessee. *Podocnemis expansa* can be surveyed by airplane at their nesting beaches in Tabuleiros, Brazil, because during their characteristically short nesting season they spending most of the daylight hours basking. Because individuals of this species are large, it may be possible for investigators to use newly designed satellite radar systems to count aggregations of basking turtles throughout the Amazon Basin without ever leaving the office!

NESTING BEACH SURVEYS

Without getting wet, buying traps, or seeing turtles, investigators can document the presence of even rare species of turtles by surveying potential nesting sites. Surveys during the nesting season, when tracks of females lead to the nest, are the most accurate. Tracks and eggs of most species can be identified at least to genus, (c.f., sympatric species of *Graptemys,* Vogt 1980a). Although nesting seasons are relatively short, species can be identified from egg fragments later in the season, after hatching or nest predation. Recently, dichotomous keys for identifying egg-shell fragments to species have been developed (R. Saumure and J. Bonin, pers. comm.). These types of nontraditional survey methods combined with trapping and basking surveys can enhance the quality of surveys for rare, threatened, or endangered species, relatively inexpensively.

BAITED HOOP TRAPS

A hoop trap is one in which a series of metal, wood, or fiberglass hoops placed at 0.5- to 1.0-m intervals are covered with nylon netting or galvanized poultry wire to form a tube. The diameter of the hoops varies according to the depth of the water where the trap will be set. A funnel entrance (small opening attached to the trap) is constructed at one (or both) end(s) of the trap using the same material. The opening of a funnel must be maintained taut so that turtles can easily force their way into the trap but have difficulty finding the opening to escape. The design of the hoop trap is about 6,000 years old (Singer 1954, as cited in Legler 1960a). In 1960, Legler simplified and standardized construction, using lightweight durable materials. The resultant *Legler Trap* has been used by researchers for more than 40 years to sample and study turtles that are attracted to bait. Fifty-cm-diameter hoops are made of 1-cm-diameter aluminum tubing, 1-m-diameter hoops of 1.5-cm tubing, and larger-diameter hoops of galvanized steel or fiberglass. Four hoops are covered with a single rectangle of 2-cm-mesh nylon fishing net to form a tube. The loose ends of the netting are inverted into the hoops at each end to form the funnel throats of the trap. The traps are kept rigid by a pair of dowel stiffeners with metal screw hooks placed on each side of the trap. These stiffeners maintain the form of the trap and, in particular, keep the throats taut, such that turtles must push their way into the trap but then have a hard time finding their way out.

Sardines in oil, canned cat food, fresh chicken parts, fish, shrimp, or other aromatic fare can be placed in a bait container made from window screen, aluminum beverage cans, or wide-mouth jars or vials. The closed container, or its lid, is punctured profusely so that the scent of the bait escapes but the bait is inaccessible. The bait containers are hung from the center of the trap. Turtles tend to stay in the trap trying to get the bait, and the natural stomach contents are not mixed with the bait. Bait should be changed daily. Traps checked at 4- to 8-h intervals usually produced a higher catch than traps checked only every 24 h. Legler (1960a) found that traps 48 cm in diameter, 83 cm long, and with a throat depth of 30 cm were the most effective at catching turtles. These traps are inexpensive to build (less than US$10 in 2008); small, light, and easy to transport and store; and easy to use. A 2- to 4-m nylon line is attached to one of the end hoops, and the trap is hurled into the water near a log, eddy, or other probable capture site. The loose end is tied to a tree, stake, or rock so that turtles or other animals in the trap cannot move away with it. An investigator can also position the trap with this line so that part of it is above water to prevent drowning of the catch. One advantage of the Legler Trap is the convenience of setting and checking it without having to get into the water.

Since Legler developed his ingenious design (Legler 1960a), it has been modified by various investigators who have substituted chicken wire, metal hoops, fiberglass hoops, and wooden hoops for Legler's original materials and attached a box at one end of the trap to hold additional turtles (see Kennet 1992). A variation developed by Iverson (1979a) is standard for catching *Kinosternon* and *Trachemys*. He used galvanized chicken wire to make his traps, which are considerably cheaper but much more cumbersome than the Legler Traps, even though the traps can be collapsed for storage and reshaped for later use. Also, otters, piranhas, and crocodiles created fewer holes in the metal traps compared to those of mesh netting. Nevertheless, I found these traps to be less effective than the standard Legler Trap at capturing turtles.

The standard hoop-trap design can be modified to trap large turtles. The most important characteristics of such traps are their lengths and throat diameters. The throats must be taut and long but with a small opening so that it is more difficult for a turtle to swim out of the trap than to swim in. Long throats keep the turtles either above the opening or below it trying to find a way out in the corners. The classic Legler Trap has throats that are 7.5 cm high and 25 cm wide. These traps are especially useful for carnivorous or omnivorous species that respond to baits, such as those in the genera *Trachemys, Kinosternon, Sternotherus, Claudius, Staurotypus, Phrynops, Trionyx, Chelydra,* and *Macrochelys*. Most herbivorous species rarely enter hoop traps unless leads (nylon fishing net with lead weights attached on the bottom edge and a float line (nylon cord with a floating nylon foam core) attached on the top, functionally a drift net) are attached in front of the traps. The leads must be the same depth as the water to be effective, that is, the turtles must not be able to swim over or below them. Instead, the turtles are herded into the traps as they try to get past the leads. The traps work on the premise that the turtles are active and hungry or sexually motivated. Trapping hungry turtles in cold water or in early spring, fall, or winter generally is not successful. *Chrysemys picta,* however, were enticed to enter traps baited with conspecifics in the early spring when these turtles were copulating but not yet feeding (Vogt 1979). A decade later, Frazer et al. (1990) independently discovered this behavior in *C. picta*. They did not, however, place their turtles in bait containers within the traps and noted that a number of the "bait turtles escaped"—a major problem with this type of trap if the throats are too short and the openings are too large.

Kennet (1992) modified the hoop-trap design to make the traps virtually escape proof. His single-throated turtle trap has an entry section with a funnel leading to the bait and a holding section from which the turtles cannot escape. The sections are joined by a rectangular tunnel of wire mesh with a one-way plastic mesh door that allows turtles to enter but not leave the holding compartment. The two-section traps are easier to position with the holding pen at least partially out of water and can be left unattended for several days without the turtles drowning or escaping. Predators, however, can be a problem.

Members of the commercial fishing industry use double-throated hoop nets of the same general design as the basic turtle trap, but their traps include seven hoops ranging from 40 to 600 cm in diameter. The long-fingered throats are attached to the second and fourth hoops, permitting the turtles to swim into the traps but making it very difficult for them to leave; because they have to force their way through the funnel mouth to enter the trap, it is almost impossible for the reverse to occur. These traps have to be set either by boat and or by walking into the water. A structure equivalent to an aquatic drift fence is often produced by attaching 15- to 30-m-long leads from the end of one trap to the end of the next. The lead is made of the same mesh-size net and extends from a float line at the surface to the bottom; a turtle cannot get above it or below it and so swims along it and ends up in a trap (Vogt 1980b). Sizes of the traps can vary depending on the depth of the water to be sampled. Turtles are not attracted to these traps by bait but merely guided into them as they try to circumvent the leads. Consequently, the traps do not target hungry carnivores and thus get a more accurate sample of the species diversity and abundance in a defined habitat. Again, the traps must be set during the season of the year when the turtles are active. Also, one must remember that some species are sit-and-wait predators, whereas others are active foragers. Nets set in front of nesting beaches are obviously going to be biased for females, although in some species males swim around more than females and are more likely to be captured. I have used this technique with great success in ponds, lakes, streams, and fast-moving rivers for all types of turtles and in all habitats from the Mississippi River of Wisconsin to the Amazon Basin in Brazil.

FIGURE 60 Fyke net deployed in a river. A Fyke net consists of two single-mouth hoop traps set on either end of a lead. The traps may be baited to attract certain species of turtles. Other species that are not attracted to bait follow the lead into the traps. (Photo courtesy of Alexandre M. Batistella.)

Fyke nets (Fig.60) represent another modification of hoop nets. In Fyke nets, a rectangular net box is attached to the front of each hoop net. A lead connects the centers of the rectangular boxes; the net is most effective if it runs from the surface to the bottom of the water. Wings may also be attached to the sides of each net, extending out from 10 to 20 m, spanning migration routes or paths to and from basking sites and diverting turtles into the traps. This modification increases the efficiency with which herbivorous turtles, which are not attracted to baits, are caught. Fyke nets are the best apparatus for catching a large number and variety of turtles from whatever aquatic habitat; all species, regardless of feeding preference, are caught in these traps. The traps are best to use for long-term studies, but they are also the most cumbersome and most expensive of all turtle traps. D. W. Tinkle and J. Congdon (pers. comm.) in their long-term turtle studies on the George Reserve (ESGR, University of Michigan) made stationary leads; whenever they were ready to sample, they put the traps in the water and attached the leads. The turtles became accustomed to moving along the leads when the traps were absent, which may have enhanced their capture effort.

All investigators must have at least some basic knowledge of where to place their traps in the habitat. All species of aquatic turtles that I have studied can be trapped effectively with turtle traps with leads in all bodies of water. We sometimes had eight species of turtles in a single trap in our studies on the Pearl River in Mississippi (C. J. McCoy and R. C. Vogt unpubl. data). Traps with smaller-diameter hoops and shorter leads (or only wings) are used in smaller bodies of water. A variety of different habitats needs to be sampled in any heterogeneous body of water in order to capture a representative sample of the turtles residing there. Traps should be set with the leads of the trap parallel to basking logs, between basking logs and deep water. *Trionyx* often bask on sand bars, and many species of turtles also nest on sand bars, so nets set parallel to sandbars or in front of nesting areas in 1 to 2 m of water are often effective. *Graptemys* can be trapped in the fast-moving portions of rivers. The nets must be set parallel to the shore line and attached to it in water 1 to 2 m deep. Traps must often be tied in several places to keep at least part of the trap out of the water and also to keep the current from rotating the traps and disabling the leads. Turtles usually forage and feed in water 0.5 to 2 m deep and within 5 to 10 m of the shoreline in deep lakes and rivers. Traps should be set parallel to the shoreline, as turtles often move along the shore line in search of prey or forage plants. Cursory observations made before setting traps are important. Distinctive bite marks on the leaves of shoreline vegetation reveal recent feeding areas of *Dermatemys*. These turtles are also fond of grazing on grasses, so setting traps in front of emergent grass banks should also increase trapping success of this species and of *Staurotypus* spp., which go to grass banks to feed on apple snails. Generally, turtles can often be trapped everywhere in shallow lakes (2–3 m deep) with aquatic vegetation throughout. I successfully collected *Pseudemys alabamensis* by stringing together 10 turtle traps with leads to span 300 m across a large bed of submerged aquatic vegetation in Mobile Bay, Alabama.

TRAMMEL NETS

When turtles are inactive or occupy deep water, they cannot be captured with Fyke nets or turtle traps, so *trammel nets* are used (Vogt 1980b). Trammel nets are made of three layers of nylon netting hung from a common float line and lead line (nylon cord with lead weight core). The two outside nets (called walling) are usually made of #9 nylon twine and have a mesh size of 30 to 75 cm, depending on the size of the turtles to be trapped. The finer inside mesh is made of lightweight multifilament gill netting, with 3- to 12-cm mesh. The inside net hangs loosely between the two outside walls and is 30 percent deeper that the outside walls. When the turtle enters the net, it pushes the lightweight netting through a larger opening in the opposite outside wall forming a pocket of netting in which it is held. The trammel net catches a much wider size range of turtles than a standard gill net. These nets are usually used in sections of 100 m and range in depth from 2 to 6 m. Several of these nets can be strung along the shore parallel to a nesting beach, across bays and inlets into lakes, parallel to the shorelines in rivers, below hibernacula, or with great success in water 4 to 6 m deep where herbivorous turtles are foraging. These nets must be checked at least every 4 h to ensure that the turtles do not drown. Trammel nets alone work only if turtles are moving. Turtles can be stimulated to move and be captured in trammel nets by driving them with a carphorn (Vogt 1980b), even when they are in winter hibernation.

A *carphorn* (Fig. 61) is a sheet-metal funnel that was designed by commercial fishermen on the Mississippi River specifically for driving carp and other schooling fish down river channels into gill nets during the colder months of the year. The funnel, constructed of heavy gauge galvanized sheet metal, is 16 cm in diameter and 21 cm long, tapering into a sleeve 4 cm in diameter. A 4-cm diameter, 3-m-long wooden pole is bolted inside the sleeve. The carphorn is plunged rapidly and forcibly into the water, making a loud popping sound, which drives the fish or turtles. If the funnel is not made from heavy-gauge sheet metal, it will collapse when pounded into the water. Any device that makes a lot of disturbance in the water is perhaps effective. Henry Bates (1863) reported Amazonian Indians beating sticks and branches on the surface of the water to drive *Podocnemis* into their nets. Amazonian fishermen today often beat the surface of the

FIGURE 61 Jack McCoy standing in the center of the canoe pounding a carphorn into the water in order to drive turtles into a trammel net. Assisting him are Kelly McCoy (his son) in the bow and Lisa Mattick (RCV's field assistant) in the stern, Glover River, Oklahoma, 1975. (Photo by R. C. Vogt.)

water with canoe paddles to drive fish and turtles out of their hiding places and into their nets.

For target turtles basking on a log, the collector should position the trammel net between the log and the turtles' escape routes as quickly as possible. This is done by driving the boat as fast as is safe to the shore near the basking log; as the boat nears the shore, the driver shifts to reverse. A second person on the bow throws out an anchor attached to a trammel net, feeds the net into the water as the boat makes a semicircle around the basking site, and then throws the anchor attached to the other end of the net into the water. Once the net is in place, the driver moves the boat back and forth between the shore and the basking log, parallel to the net, while the second person plunges the carphorn into the water. I do not know how the sound carries underwater, but turtles move rapidly away in response, entering the net; 50 to 100 turtles can be caught in a matter of minutes. Turtles can be captured this way even when they are hibernating or estivating, as long as the sites where they congregate are known (Vogt 1980b). To be most effective at hibernacula or estivating sites, trammel nets should be weighted so that they sink to the bottom. We have used this technique to capture estivating *Dermatemys* in the deep whirlpools of the Rio Lacantún, in Chiapas, Mexico; for *Podocnemis unifilis* in the Brazilian Amazon; and for the species of hibernating *Graptemys* in the Mississippi River in Wisconsin. Trammel nets are also good for rapidly sampling ponds with diameters of 100 to 300 m. The net is set in the center of the pond, and then the carphorn is pounded into the water from the shore on both sides of the net. Within an hour a large proportion of the turtles will have been captured. This procedure eliminates the wait for the trapping results, as well as loss of nets or traps, and the stomach contents of the turtles are fresh and unadulterated by trap bait.

Data from Terrestrial and Freshwater Turtles

Documenting the presence of turtles and analyzing their community structure or population trends are complex processes; sampling by land, air, and water may be required to amass sufficient data. All sampling methods are probably biased toward a particular sex, size class, or species of turtle. Ream and Ream (1966) discussed the problems with some of the methods. With long-term mark and recapture studies, however, biases can be detected and corrected in the analysis. One problem related to sampling bias is the misconception that the sex ratio in a turtle population should be 1:1 and that any drastic deviation from that ratio indicates a sampling bias. We have documented unequivocally, however, that sex is determined by incubation temperature in many species of turtles (Bull and Vogt 1979), that hatchling sex ratios of some species in any given year can be highly biased in favor of one sex or the other (Vogt and Bull 1984), and that the adult sex ratio of some species of turtles is highly biased in nature no matter how they are collected (4:1 females to male, Vogt 1980a); consequently, some of these techniques may not be biased.

Turtles densities are usually reported as number of turtles caught per trap hour per m of shoreline, or as number of turtles caught per net hour per m of trammel net. Basking turtles are reported as number seen per km of river or shoreline during a set period. Nest counts are reported per hectare of nesting habitat. Dead turtles on road (DTOR) are reported as number per km of road.

Marine Turtles

Documenting the presence of any of the seven species of marine turtles on a nesting beach can be a relatively simple process of knowing when nesting occurs and then walking the beach at night with a flashlight and identifying and counting each turtle encountered. Nests and tracks can also be counted. Because many species of sea turtles lay multiple clutches in a season and individuals of some species do not reproduce every year, one must be careful when speculating about the number of reproductive females of each species that uses a particular nesting beach. It is perhaps safer to calculate the number of nests that are constructed and the number of hatchlings produced to determine the potential importance of a nesting beach for a particular species. With only seven species of marine turtles, investigators can easily learn to identify them and their tracks, nests, and eggs by sight. Investigators with all-terrain vehicles (ATVs) can transverse hundreds of kilometers of beaches each day counting turtle tracks and nests. Many researchers have counted nests and tracks during airplane flights. Bjorndal (1999) reported that even though sea turtles spend at most 1 percent of their lives on or around nesting beaches, about 90 percent of the literature on sea turtle biology is based on studies at nesting beaches. The reasons for this are obvious; in Bjorndal's (1999, p. 12) words, "Anyone who has spent days on rough seas searching for turtles and finding them at a rate of one per day cannot help but think wistfully of the colleague working on the nesting beach who, during a pleasant evening stroll, is certain to encounter many more turtles." As long as granting agencies support additional beach studies in conjunction with the numerous sea turtle conservation programs, rather than insisting that funding be used to support new and innovative research and management during the other 99 percent of the lives of these creatures, populations will continue to dwindle. Information on habitat use of all species and size classes of turtles when they are away from the nesting beaches is desperately needed. Nevertheless, data on the size and condition of nesting habitats, density of nests, survivorship of nests, and nest temperatures are important. With an ever-decreasing amount of money available for conservation and management, it will be impossible to protect all beaches; beaches with the highest survivorships, densities, species diversities, and numbers of female hatchlings should be of highest priority for protection (Vogt 1994).

Acknowledgments

I would like to thank my mentors, the late Jack McCoy and John M. Legler, for the hundreds of hours they spent over the last 40 years suffering and answering my questions. I also recognize Mike Ewert for finally admitting that driving turtles into a trap with a carp horn is a more effective and efficient technique than hand-capturing or noodling. I also thank my many assistants who suffered my wrath and impatience while field testing these methods over the years: Marsha Christiansen, Lisa Mattick, Kris Klevickis, Jan Salick, Mike Pappas, Oscar Flores Villela, Claudia Carnevale, Veronica Gonzales, Marco Antonio Lopez, Nora Tamal Lopez, Paco Soberon, Alan Jaslow, Marcelo Paxtian, Santos Mataperro, Rafael Bernard, Oneide Ferreira da Cruz, Mario Pinto Castro, Augustin El Gato, Virginia Bernard Diniz, Camila Rudge Ferrara, Larrisa Schneider, and Carla Eisenberg.

Alternative Methods for Sampling Freshwater Turtles and Squamates

Thomas S. B. Akre, John D. Willson, and Thomas P. Wilson

Conventional techniques for sampling aquatic turtles and terrestrial squamates are well developed with a proven track record (Lagler 1943; Balgooyen 1977; Plummer 1979; Jones 1986; Karns 1986; Fitch 1987; Dunham et al. 1988; Gibbons 1990; Heyer et al. 1994; Schemnitz 1996). However, no single capture method is effective in all habitats, nor can it be applied to all species and all life stages with equal success (Moll and Legler 1971; Campbell and Christman 1982; Gibbons 1983, 1990). Certain aquatic habitats may be challenging to sample because they are relatively remote and/or because of the nature of the waterscape and its substrate and vegetation (e.g., small fast-flowing rivers, forested swamps, bogs, or ephemeral wetlands). Just as often, aquatic species can be difficult to sample because of aspects of their life history (e.g., diet, microhabitat use, ontogenetic variation, or relative abundance). For example, the turtles *Pseudemys concinna, Clemmys guttata,* and *Graptemys* spp. do not respond well to baited aquatic traps, but all have been readily captured using other techniques (Chaney and Smith 1950; Plummer 1979; Vogt 1980b; Gibbons 1990; Graham 1995). Likewise, snakes that favor aquatic vegetation (e.g., *Regina alleni, Seminatrix pygaea*) can be captured in significantly greater numbers by straining aquatic vegetation than by aquatic funnel trapping or visual surveys (Godley 1980, 1982). Therefore, effective sampling often requires specialized techniques that suit the habitat and reflect the life-history traits and ecology of the target species or assemblage.

Below we describe several methods for sampling turtles, snakes, and lizards in aquatic habitats and comment on the strengths and weaknesses of each technique, special considerations, and particularly pertinent applications. Three factors should be considered regardless of the study design, target taxa, or habitat. First is capture probability, which can be enhanced by advanced familiarity with the study area and consideration of season and weather. Second, close attention should be paid to the methods used by indigenous peoples, which have proven fruitful (e.g., see Lamar and Medem 1982; Luiselli 1998; Gaulke et al. 1999). Third, multiple direct and indirect methods (*sensu* Vogt 1980b) should be used across habitats over a long period to maximize sample size and minimize capture bias and its influence on interpretation of data (Ream and Ream 1966; Wilbur 1967; Moll and Legler 1971; Overton 1971; Vogt 1980b; Gibbons 1983, 1990; Henke 1998). Finally, new techniques for the ancient problem of capturing organisms emerge regularly. We suggest that our list, while not exhaustive, is thorough and therefore includes the basic methods. Nonetheless, an investigator should always consult the recent literature when developing a study design.

Active Capture

VISUAL SURVEYS

Visual surveys are often used for reconnaissance of turtle presence, habitat use, activity, and abundance and can also be used for basking aquatic snakes and certain lizards (e.g., *Varanus* spp., *Tupinambis* spp.). With a well-honed search image, the presence of turtles, snakes, and large lizards can be verified and quantified by scanning the habitat with the unaided eye, binoculars, or spotting telescopes. Scanning from an elevated location or a blind enhances the viewing area without provoking a flight response from basking turtles (Moll and Legler 1971; Holland 1994; Lindemann 1996). Researchers have used visual surveys to locate and count surface basking or breathing *Apalone spinifera, Chelydra serpentina, Chrysemys picta,* and *Kinosternon* spp. (Mosiman and Bider 1960; Webb and Legler 1960; Teska 1976; Lovich 1988; Iverson 1989) as well as aerial basking (i.e., from a raised location such as a log or rock) *Graptemys* spp., *Pseudemys concinna, Rafetus euphraticus,* and *Sternotherus carinatus* (Chaney and Smith 1950; Conant et al. 1964; Moll 1986; Lindeman 1996, 1998, 1999; Taskavak and Atatür 1998). Scanning from a boat has been used successfully to locate and capture *Chelydra serpentina, Chrysemys picta,* and *Emydoidea blandingii* and for distribution surveys of *Actinemys marmorata* and *Dermatemys mawii* (Lagler 1943; Mosimann and Bider 1960; Gibbons 1968a; Moll 1986; Holland 1994).

HAND CAPTURE

Hand capture has been used in diverse habitats for sampling many aquatic reptile species (e.g., Mosimann and Bider 1960; Mahmoud 1969; Moll 1976; Mushinsky and Hebrard 1977; Mushinsky et al. 1980; Auffenberg 1981; Hulse 1982; Lamar and Medem 1982; Shively and Jackson 1985; Dundee and Rossman 1989; Gibbons 1990; White and Moll 1992; Greene et al. 1994, 1999; Flores-Villela and Zug 1995; Souza and Abe 1995, 1997; Magnusson, Cardoso de Lima, Lopes da Costa, and Vogt 1997; Bury and Germano 1998; Greshock 1998; Luiselli 1998; Mills 2002). Many species can be captured effectively by hand, dipnet, or pole snare while the investigator walks a shoreline, wades, floats, floats in an inner tube, or rides in a small boat. Nonetheless, success will likely vary by target species and the skill of the investigator (Moll and Legler 1971; Gibbons 1983). Some species may be readily captured when approached, but others may have to be ambushed (e.g., *Apalone mutica, Phrynops*

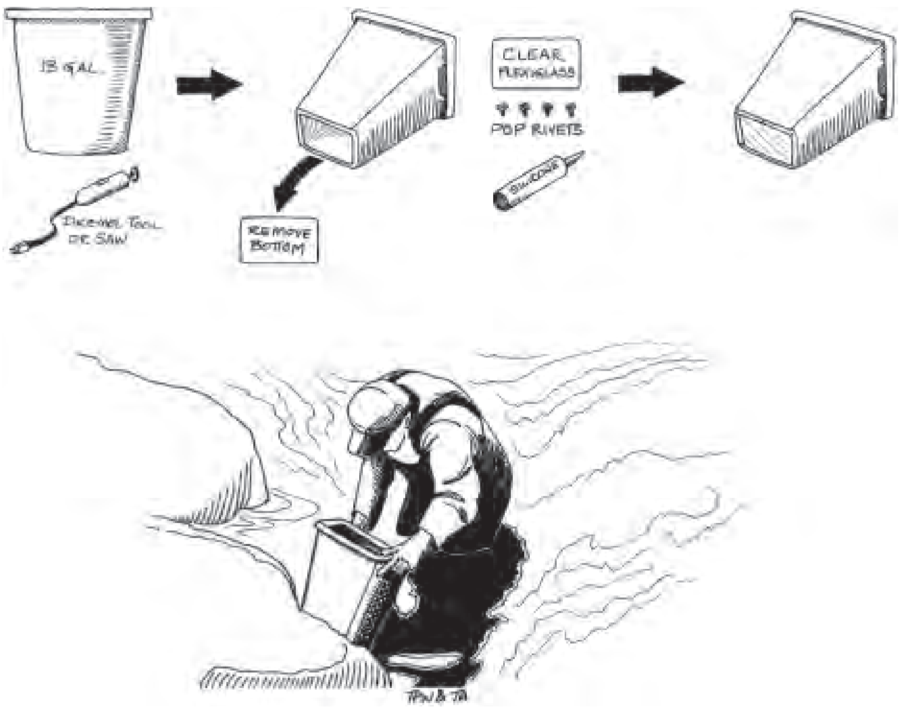

FIGURE 62 Trash-can-model aquatic viewscope used to locate and observe turtles that are underwater.

williamsi, and *Trachemys stejnegeri*; Hodson and Pearson 1943; Fitch and Plummer 1975; Ward et al. 1976; Buskirk 1989). When the element of surprise is necessary to capture reptiles as they bask over water, the researcher can float with his or her body concealed below the water's surface or use a floating blind (Bider and Hoek 1971; Shealy 1976; Gibbons 1983; Mills 2002). One drawback to hand capture is that only conspicuous, active animals are typically captured, which may result age and/or sex-biased data (Dunham et al. 1988).

VIEWSCOPES

Aquatic viewscopes have long been used in aquatic ecology and fisheries research (M. J. Pinder, pers. comm.) and can be adapted to aid in turtle capture in clear shallow ponds, streams, and rivers. Although aquascope designs vary, they all function by breaking the water's surface and reducing surface distortion and interference from reflected light. An aquascope can provide an alternative to diving if the researcher is outfitted with chest waders and the substrate can be reached by hand or dipnet. A small plastic trash can with a silicone-sealed clear, Plexiglas bottom (Fig. 62) is invaluable for observing and capturing juvenile and adult *Glyptemys insculpta* in the cooler months (Akre 2002). Likewise, fiber-optic scopes can be used successfully to locate *Gopherus agassizii* in burrows, *Mauremys japonica* under water, and *Sistrurus catenatus* in crayfish burrows and other underground refugia (Cairns 1983; Yabe 1992; Purcell 1997; Mauger and Wilson 1999; Wilson et al. 1999). Both technologies are particularly useful for locating animals that would otherwise be missed, such as those under cutbanks and submerged structures where vision is normally obscured.

NIGHT SPOTTING

Spotlighting at night with a high-powered lamp has led to the capture of many aquatic reptiles, including both diurnal and nocturnal species. Lagler (1943) first reported success in capturing *Sternotherus odoratus* from a boat using a dipnet and a jacklight. Ernst, Cox, and Marion (1983, 1989) found that wading at night with a lantern was second only to trapping for collecting *S. depressus*. Gibbons (1990) located *Trachemys scripta* with a flashlight in shallow portions of some ponds as they lay quiescent on the bottom during the winter. Moll (1986) used a motorboat and a spotlight to survey *Dermatemys mawii* as they fed and loafed at the surface in lagoons and rivers in Belize. Chaney and Smith (1950) captured hundreds of riverine turtles (e.g., *Apalone spinifera, Chelydra serpentina, Graptemys* spp., *Macrochelys temminckii, Pseudemys concinna, Sternotherus carinatus,* and *Trachemys scripta*) by using a motorboat at night to visit areas of known daytime basking aggregations and then spotlighting and dipnetting the turtles.

Many aquatic snake species are primarily nocturnal, particularly during hot weather. In some instances, these species can be captured effectively at night by carefully searching aquatic habitats with the aid of a flashlight or spotlight. Neill (1964) used this technique to capture extraordinary numbers of rainbow snakes (*Farancia erytrogramma*) in the southeastern United States. Likewise, nocturnal surveys of *Nerodia* spp. and *Regina grahamii* were substantially more effective than diurnal surveys during the hot summer months in Louisiana (Mushinsky and Hebrard 1977; and Mushinsky et al. (1980). Additionally, Corben and Fellers (2001) described a technique for viewing the eyeshine of small reptiles and amphibians that would doubtless prove useful in aquatic surveys of squamates.

DIVING

Snorkeling and scuba diving have proven invaluable for sampling turtles in clear water. Carr and Marchand (1942) invented a technique called *water goggling* in which a diver in the water alongside and propelled by a motorboat uses a facemask to scan for turtles (Marchand 1945). When a turtle is spotted, the diver pushes off the boat and swims after it. This technique allows the investigator to cover more area than with snorkeling alone. Nonetheless, with fins, a facemask, and a snorkel tube, divers in any clear, open aquatic habitat can capture many species of turtle by hand (Gibbons 1968a, 1968b, 1983; Jackson 1969; Moll and Legler 1971; Shealy 1976; Iverson 1977, 1979b; Legler 1978; Legler and Cann 1980; Shively and Jackson 1985; Kramer 1986; Moll 1986, 1990, 1994; Buskirk 1989; White and Moll 1992; Kuchling and Mittermeier 1993; Holland 1994; Magnusson, Cardoso de Lima, Lopes da Costa, and Vogt 1997; Allanson and Georges 1999). Scuba has been employed less frequently, but Graham and Graham (1992, 1997) and Ultsch et al. (2000) used it year round to observe and capture *Apalone spinifera* and *Graptemys geographica* in a Vermont river. Both of these methods greatly enhance sampling success by providing the researcher direct access to turtles in their aquatic habitats.

TRACKING

When turtles are not readily visible, their presence can still be recorded based on sign they leave. For example, individuals of *Apalone mutica* and *A. spinifera* in transit across beaches leave foot and tail tracks, whereas buried individuals leave circles of disturbed sand (Lyons 1972; Williams 1975; Plummer 1977a). Visual tracking of this type has also been used to locate and capture *Kachuga tentoria, Amyda cartilaginea, Cyclemys dentata,* and *Heosemys grandis* in streams and rivers (Singh 1985; Thirakhupt and van Dijk 1994).

Scent-tracking dogs have long been used in wildlife studies and by local hunters for the Asian turtle trade (Zwickel 1980; Hendrie 2000; Platt et al. 2000). Their potential value for turtle research was first noted by Carr (1952), and since then, a few investigators have used dogs to locate turtles (e.g., *Terrapene* and *Kinosternon* spp.; Schwartz and Schwartz 1974; Morales-Verdeja and Vogt 1997).

BLIND CAPTURE

Nonvisual capture takes many forms and may be tailored to the specific study design. Researchers can "muddle" or "noodle" for their quarry by blindly probing the substrate with their hands and feet, or a pole, to feel for the presence of certain turtles and large aquatic snakes (Lagler 1943). This technique has been used in several different species in many different habitats (e.g., *Apalone spinifera, Chelodina* spp., *Chelydra serpentina, Clemmys guttata, Cyclemys dentata, Glyptemys* spp., *Kinosternon* spp., *Lissemys punctata, Terrapene coahuila,* and *Trachemys* spp. (Bishop and Schoonmacher 1921; Hodson and Pearson 1943; Mosimann and Bider 1960; Webb et al. 1963; Lyons 1972; Rhodin and Mittermeier 1976; Auffenberg 1981; Ernst 1976; Ernst, Zappalorti, and Lovich 1989; Gibbons 1990; Moll 1990; Thirakhupt and van Dijk 1994; Lewis and Ritzenthaler 1997; Lewis and Faulhaber 1999). Although muddling had been most widely used for capturing turtles, Rivas (2000) successfully located green anacondas (*Eunectes murinus*) by prodding shallow hyacinth beds with a pole or his feet in the llanos of Venezuela. In each case, the researcher learned to feel or hear a cue indicating the location of an animal. For additional information, see "Hand Capture" in the section on "Detecting and Capturing Turtles in Freshwater Habitats," above.

STRAINING AQUATIC VEGETATION

Shallow aquatic habitats with abundant vegetation can support large numbers of reptiles but are difficult to sample using conventional methods (Goin 1943; Godley 1982). Often, animals can be located by raking the substrate or vegetation with a potato or garden rake (Goin 1942; Plummer 1977b; Ernst, Cox, and Marion 1989). In addition, Godley (1982) modified a sieve originally described by Goin (1942) and used it to sample aquatic snakes in beds of Florida water hyacinth (*Eichhornia crassipes*). Large numbers of *Regina alleni, Seminatrix pygaea, Farancia abacura, Nerodia floridana,* and *N. fasciata* were captured with the sieve, which consisted of a 100-×50-×10-cm wood frame with a bottom of plastic window screen supported beneath by 0.5-in hardware cloth (Godley 1980, 1982). These sieves can also be used to sample small turtles, semi-aquatic lizards, and other aquatic reptiles. Additionally, it is more quantitative than other methods, as it allows for complete sampling of a known area of habitat and can be used to calculate reptile density and biomass (Godley 1980, 1982).

ELECTROSHOCKING

Electroshocking is a method common to fisheries research (Murphy and Willis 1996) that may be useful for sampling reptiles in clear shallow water from which stunned animals can easily be retrieved (Gunning and Lewis 1957; Harris 1965; Dobie 1971). Although published accounts of electroshocking reptiles are few, T. Mills (pers. comm.) successfully captured *Nerodia floridana* and *N. taxispilota* in swamps and streams of South Carolina using this technique. In addition, ichthyologists have reported capturing *Glyptemys insculpta* and *Farancia erytrogramma* (a species notoriously difficult to find) while electroshocking eels in streams and small rivers (D. Fletcher, pers. comm.; F. Frenzel, pers. comm.).

Trapping

AQUATIC FUNNEL TRAPS

Aquatic funnel traps are among the most effective means of sampling inconspicuous aquatic squamates and have been used as the primary sampling technique in numerous studies of aquatic snakes (e.g., Greene et al. 1994, 1999; Seigel, Gibbons, and Lynch 1995; Seigel, Loraine, and Gibbons 1995). Although numerous funnel-trap variations have been described, commercially available minnow, crawfish, or eel traps remain the standard for aquatic situations (Adams et al. 1997). These are generally constructed of metal hardware cloth, tough plastic, nylon mesh, or wood (Adams et al. 1997). Traps are generally set in shallow water, allowing captured animals access to air (Adams et al. 1997). However, Casazza et al. (2000) attached polystyrene floats alongside eel pots to allow for surface trapping of

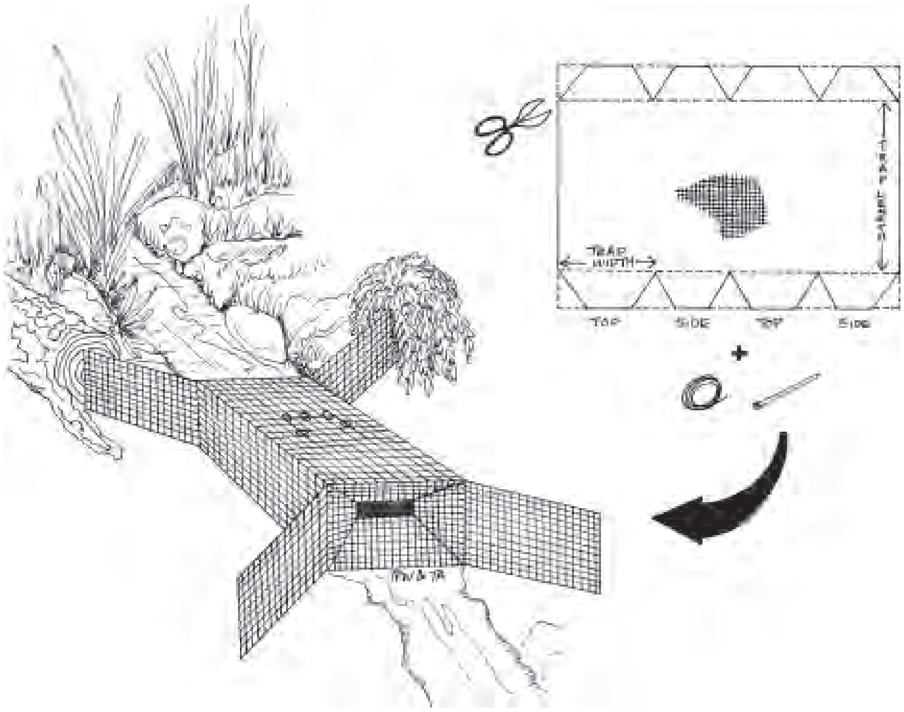

FIGURE 63 Swing-door box trap for catching turtles. The hanging door opens in only one direction, so that once a turtle enters the trap, it is unable to exit.

Thamnophis gigas in deep-water habitats. Although funnel traps will often "bait themselves" with bycatch, Keck (1994a) found that traps purposefully baited with dead sunfish (*Lepomis* sp.) and tadpoles (*Lithobates catesbeianus*) captured more than twice the number of semi-aquatic snakes than did unbaited traps in Texas ponds.

INTERRUPTION TRAPS

Small- to medium-size traps constructed of poultry netting or hardware cloth, when placed in a naturally occurring bottleneck, interrupt the movement of turtles and squamates and trap the animals without bait. These interruption traps can be constructed to fit any size passage in any microhabitat, aquatic or terrestrial. Funnel traps, which have been used in numerous turtle studies, have an opening at each end to lead turtles into a holding chamber (Legler 1960a; Gibbons 1968b; Iverson 1979a). Swing-door box traps have a hanging door that opens in only one direction so that once a turtle has entered it is unable to exit. Both trap designs may be complemented with wings (i.e., drift fences) constructed of wire or fencing that lead off each side at a 45-degree angle (Fig. 63). Interruption traps have been used to capture *Clemmys* and *Glyptemys* spp., among many other species (Ernst 1976; Wilson 1994; Akre 2002).

LURES

Researchers have long suggested the value of placing female turtles into hoop nets (see "Baited Hoop Traps" in the section on "Detecting and Capturing Turtles in Freshwater Habitats," above) to lure conspecifics into the trap (Cagle and Chaney 1950; Plummer 1979; Gibbons 1983; Dunham et al. 1988). Frazer et al. (1990) evaluated this technique and concluded that turtles are attracted to traps containing conspecifics. Likewise, Mansfield et al. (1998) placed hand-painted decoys in traps and successfully attracted *Clemmys guttata*. This technique evidently can also be used to sample aquatic squamates and the addition of live animals or decoys to traps should be considered whenever practical.

AQUATIC DRIFT FENCES

Traps placed along natural "drift fences" such as submerged logs, steep shorelines, and swamp channels capitalize on the natural thigmotaxis by capturing animals that are moving along these barriers (Fitch 1987; Keck 1994a). Enge (1997a) provides detailed descriptions of aquatic drift fence construction using silt fencing and wire funnel traps, but the efficacy of drift fences in comparison with traditional funnel traps for capturing aquatic reptiles is poorly established (Willson and Dorcas 2004b). Willson and Dorcas (2004b) described options of a similar design, using collapsible nylon mesh minnow traps along short (3-m) sections of silt fencing. This design of drift fence captured nearly three times the number of amphibians than unfenced traps did in a temporary wetland in North Carolina. Although further research is necessary, it is likely that aquatic drift fences would prove similarly effective for capturing aquatic squamates and small turtles. Important considerations in construction of aquatic drift fences are that trap openings lie flush against the fencing and that some part of the trap remains above water to ensure that trapped animals have access to air (Enge 1997a; Willson and Dorcas 2004b).

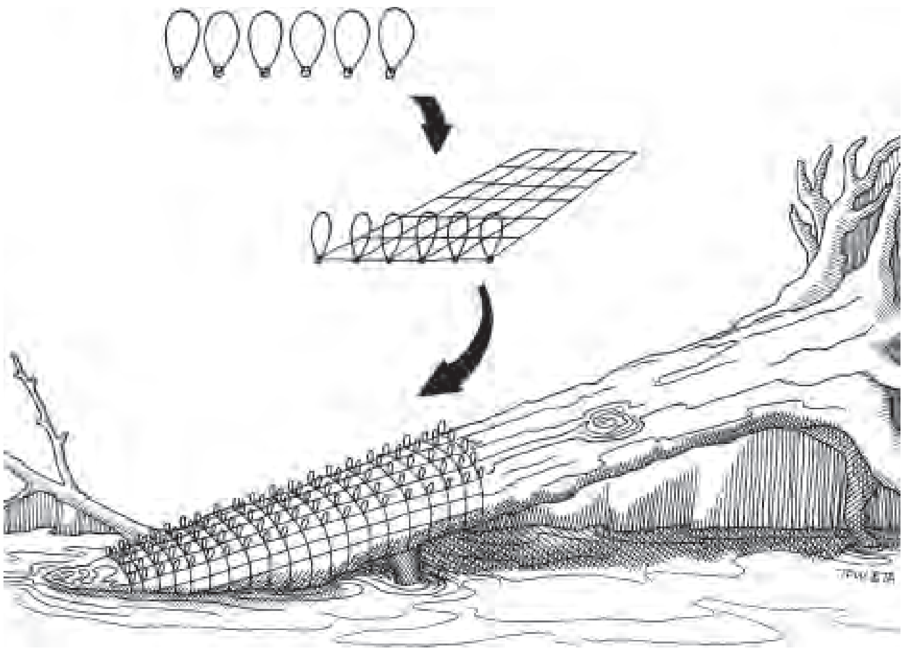

FIGURE 64 Bal-chatri trap made from a piece of wire mesh (e.g., hardware cloth, chicken wire) to which a series of erect slip nooses made of monofilament line are attached. When turtles (or other animals) cross the wire, the loops act as snares.

MIST NETTING

Mist netting, a trapping method commonly used in ornithology (Bub 1991) and not unlike gillnetting for fish and turtles, has been used to capture aquatic snakes (*Nerodia rhombifer, N. erythrogaster,* and *Agkistrodon piscivorus*) in Oklahoma streams and ponds (Lutterschmidt and Schaefer 1996). However, the method may be biased toward the capture of large snakes, and removal of venomous species from the net may be problematic (see "Handling Live Reptiles," in Chapter 8).

SNARES

Traps employing a snare mechanism are commonly used in studies of mammals and birds. The bal-chatri trap, invented by Berger and Mueller (1959) consists of a wire mesh platform and a series of erect loops made of a monofilament line that act as snares (Fig. 64). Braid (1974) suggested its use on/around basking sites or in areas of high use, and found it effective in the collection of *Chrysemys picta* and *Clemmys guttata*. Shively and Jackson (1985) used it as their principal method for capturing *Graptemys* spp. Reed et al. (2000) found a baited version of this design to be the most effective method for the capture of *Varanus indicus* in the Mariana Islands. Although effective, bal-chatri traps may harm incidentally captured wildlife and should be checked frequently to reduce the chance of injury and mortality (Vogt 1980b; Reed et al. 2000).

Varanid lizards have been captured effectively in terrestrial and arboreal habitats using a variety of methods, including burrows excavation, trapping, noosing, pit trapping, and snaring (Auliya and Erdelen 1999). Of these techniques, only snares baited with meat or fish proved useful for capture of large aquatic monitors (e.g., *Varanus salvator*; Shine et al. 1996), and Gaulke et al. (1999) found that lengthening the string or using a smaller angle of stick greatly reduced incidence of injury. In contrast, Auliya and Erdelen (1999) concluded that the bamboo box trap (similar to a conventional live trap with a trapdoor and solid floor to prevent lizards from digging out) baited with meat or fish was the most effective trap for *V. salvator*. They further improved this design by placing the trap on a bamboo raft to allow trapping of flooded areas and prevent loss of traps in floods.

Application of Terrestrial Techniques for Aquatic Species

Despite their "aquatic" designation, many freshwater reptile species are found regularly in terrestrial habitats, especially those adjacent to aquatic habitats, particularly when dispersing or moving between ponds (e.g., Fitch 1949; Hellman and Telford 1956; Campbell and Christman 1982; Dalrymple et al. 1991; Bernardino and Dalrymple 1992; Tucker 1995). Consequently, they are often registered or captured with methods normally deployed for surveying terrestrial species. These techniques are discussed at length in other sections (e.g., see above and Chapters 5 and 13) and so will be mentioned here only briefly.

Road riding (see "Road Riding," in Chapter 13) can be particularly useful for species inventories and often allows many species to be recorded in a short time. In addition, road kills can provide specimens. Artificial cover objects (see "Sampling with Artificial Cover," in Chapter 13) is another terrestrial technique that can be applied to sample aquatic species, particularly if the cover objects are near to or even partially submerged in water (Grant et al. 1992; Seigel, Loraine, and Gibbons 1995). Likewise, terrestrial drift fences and traps (see "Funnel Traps, Pitfall Traps, and Drift Fences," in Chapter 5, and "Pitfall-Trap Surveys," in Chapter 13) located near aquatic habitats will generally capture the most aquatic species. In fact, terrestrial drift fences have served as the primary sampling method for studies of many aquatic turtle and snake species (e.g., Gibbons et al. 1977; Semlitsch et al. 1988; Dodd 1992a, 1993a; Seigel, Gibbons, and Lynch 1995; Seigel, Loraine, and Gibbons 1995).

Acknowledgements

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Sampling Marine and Estuarial Reptiles

Harold K. Voris and John C. Murphy

When one thinks of environments occupied by reptiles, saltwater and brackish-water habitats are not the first that come to mind. However, a variety of species routinely occupy marine habitats, and others are occasional visitors. Schmidt (1951) and Neill (1958) compiled global surveys of reptile species known to use brackish and saltwater environments, as well as species known to occur in habitats adjacent to the sea and estuaries. In this section, we focus on reptile species that occupy marine habitats primarily, including salt marshes, estuaries, mangroves, and other coastal environments.

Among modern reptiles, snakes are by far the most successful in marine habitats, although the Galapagos Marine Iguana (*Amblyrhynchus cristatus*), one crocodilian, the Salt Water Crocodile (*Crocodylus porosus*), and seven species of sea turtles (families Cheloniidae and Dermochelyidae) also make use of this habitat. One species of file snake (*Acrochordus granulatus,* Acrochordidae) is found almost exclusively in brackish water and marine habitats. The other two species, *A. javanicus* and *A. arafurae,* are primarily freshwater species, but they too have been reported from brackish water and marine environments. Most of the 37 species of homalopsid snakes (Homalopsidae) are freshwater, semi-aquatic, and aquatic species, but at least 10 species spend part or much of their lives in brackish or salt water (Murphy 2007). See Pauwels et al. (2008) for a summary of global diversity of freshwater snakes.

Sea snakes (Subfamily Hydrophiinae, Family Elapidae) are usually marine, but a few species have returned to freshwater. The Hydrophiinae are the most diverse group of marine snakes today and represent a relatively recent radiation (Lukoschek and Keogh 2006). Culotta and Pickwell (1993) have compiled an extensive bibliography on the Hydrophiinae.

Sea kraits of the genus *Laticauda* are also included in the family Elapidae but represent an independent lineage from the Hydrophiinae that some recognize as a separate Subfamily Laticaudinae. The Sea kraits are semi-aquatic in island environments, and while well adapted for marine life with a paddle tail, they bask, mate, digest food, and lay eggs on land. Keogh (1998), Dunson (1975a), Heatwole (1999), Heatwole, et al. (2005), and Ineich and LaBoute (2002) have discussed their biology.

Other lineages of lizards and snakes have scattered species or populations that have specialized in coastal habitats. Although many of these species are terrestrial or arboreal, they also use marine resources. For example, arboreal Burmese Vine Snakes (*Ahaetulla fronticincta,* Colubridae) ambush marine mudskippers (fish in the family Gobiidae, subfamily Oxudercinae) from arboreal perches overhanging the water (Smith 1943).

Three North American natricines, the Saltmarsh Watersnake (*Nerodia clarkii* ssp.), the Marsh Brownsnake (*Storeria dekayi limnetes*), and the Cape Gartersnake (*Thamnophis valida*), are coastal snakes that use mangroves and salt marsh habitats (Conant 1969; Gibbons and Dorcas 2004; Anderson 1961; Rossman et al. 1996). Additionally, some North America populations of the semi-aquatic pit viper, the Florida Cottonmouth (*Agkistrodon piscivorous conanti*), use mangroves and salt marshes (Lillywhite et al. 2008). In the Neotropics, some species of the aquatic and semi-aquatic dipsadid genera *Helicops, Hydrops, Liophis,* and *Tretanorhinus* use freshwater and brackish water in coastal habitats to varying degrees.

In North Africa and Europe, three natricid species use coastal habitats: the Viperine Snake, *Natrix maura*; the Grass Snake, *N. natrix*; and the Dice Snake, *N. tessellata* (Schleich et al. 1996; Sindaco et al. 2006). Two African snakes (*Grayia smythii* and *Crotaphopeltis hotamboeia*) of uncertain lineages occur in brackish-water, mangrove habitats as well as in freshwater (Luiselli et al. 2002; Kelly et al. 2009).

In Southeast Asia, the Mangrove Pitviper (*Cryptelytrops purpureomaculatus*), the Mangrove Snake (*Boiga dendrophilia*), and the Hamadryad (*Ophiophagus hannah*) inhabit mangroves, but like the Vine Snake, these species are mostly arboreal and terrestrial, and therefore, unlikely to spend significant time in the water.

Habitats

ESTUARIES AND RIVER MOUTHS

All three species of file snakes (*Acrochordus* spp.) have been reported from these habitats. Many species of Hydrophiinae use estuaries and river mouths, particularly *Aipysurus eydouxii, Enhydrina, Hydrelaps, Lapemis, Parahydrophis,* and some *Hydrophis* (e.g., *brookii, lapemoides, melanosoma, macdowelli, obscurus, ornatus, torquatus,* and *vorisi*). It is also likely that the 10 species of homalopsids known to use brackish and salt waters use these environments at least on occasion. Many homalopsids that are primarily freshwater species may live in river mouths. For example, at least six species of the mostly freshwater *Enhydris* have populations in river mouths, and three of these species (*E. maculosa, E. pakistanica, E. vorisi*), appear restricted to river deltas. A few of the natricids and dipsadids previously discussed also use these habitats.

MANGROVE SWAMPS

North American aquatic snakes that use mangrove habitats include *Nerodia clarkii* ssp. and some populations of *Agkistrodon piscivorous conanti*. Wharton (1969) and Lillywhite et al. (2008) reported *A. p. conanti* scavenging for food under nesting herons and cormorants as well as in the intertidal zone. In the Neotropics *Helicops, Hydrops, Liophis,* and *Tretanorhinus* may be present in mangroves at least occasionally. In Australasia, mangroves are used by homalopsids, particularly *Cerberus, Cantoria annulata, Fordonia,* and *Myron*. In Southeast Asia *Bitia, Cerberus, Cantoria violacea, Fordonia,* and *Gerarda* use these habitats.

SALT MARSHES

Few snakes are specialized for inhabiting salt marshes; even those that use mangroves, estuaries, and river deltas are unlikely to occur there. North America's *Nerodia clarkii* and *Storeria dekayi limnetes* are known to use salt marshes. Bennett's Mud Snake (*Enhydris bennetti*), a homalopsid, is frequently reported from the salt marshes and mangroves of coastal China, from Hong Kong to Hainan and North Vietnam (Murphy 2007; Nguyen et al. 2009). Based on current knowledge, this species appears to be an intertidal specialist (Murphy 2007). In Scilly, Luiselli et al. (2005) found *Natrix n. sicula* feeding on marine fish in a highly degraded coastal marsh. The terrestrial snakes *Coluber viridiflavus* and *Elaphe lineata,* as well as several species of terrestrial lizard, were also collected at that study site.

Sea-grass beds may occur in relatively clear water, facilitating visual inspection of snakes. Kerford, et al. (2008) were able to count Bar-bellied Sea Snakes (*Hydrophis elegans*) from a boat traveling about 7 km per hour in water that was approximately 3.5 m deep at Shark Bay, Western Australia.

Capture

Marine and estuarial environments present a huge array of structural diversity. Thus, the best technique to use in one habitat may not function in another habitat. In addition, the daily tidal fluctuations, as well as variation in substrate type (ranging from rock and sand to mud) and vegetation density (from algal mats to dense Nipa Palm [*Nypa fruticans*] or mangrove), make the intertidal habitat particularly challenging to researchers wishing to sample the herpetofauna. We have successfully used funnel traps (see "Funnel Traps, Pitfall Traps, and Drift Fences," under "Trapping," in Chapter 5) to sample freshwater populations of homalopsids in Thailand, but these traps are not practical in tidal environments, because of the tidal fluctuations and water movement. A summary of sampling techniques follows.

OTTER TRAWLS

Otter trawling, or *dragging*, which is commonly used in commercial fisheries, involves dragging a large net behind a boat. The net may be dragged along the bottom or in the water column behind the vessel and is attached to the vessel by ropes or steel cable. The net is held open by two large "doors," which are attached to either side of the net. Periodically, the net is hauled aboard the vessel, and the catch is spilled from the bag before the net is redeployed. Mouths-of-Otter trawls range from 5 to 20 m or more across. Sea snakes are frequently part of the bycatch. Through contracts with fishermen, an investigator can obtain large numbers of sea snakes, but details on where the snakes were collected, the nature of substrate, and the depth of the water are nearly always lacking. This problem is compounded because today's modern trawlers routinely travel many hundreds of kilometers over 1 or 2 weeks in search of fish or prawns. In addition, the trawlers often deploy their nets while moving from one fishing ground to another. Thus, although trawlers may provide a large number of specimens, ecological and geographic data are usually missing (Fig. 65). Extensive collections of marine snakes have been made in Tonking Bay (Shuntov 1962) in the South China Sea (Smith 1926; Shuntov 1966; Lemen and Voris 1981), on the Sahul Shelf (Shuntov 1971), in the Gulf of Carpentaria (Wassenberg et al. 1994; Fry et al. 2001), in the Gulf of Thailand (Tu 1974), and off the coast of Borneo (Voris 1964; Stuebing and Voris 1990; Han et al. 1991).

FIGURE 65 Catch from a small commercial otter trawl operating ca. 20 km northeast of Endau, Malaysia, in the South China Sea, 1971. The bycatch is a sea snake, *Thalassophis anomalus*. (Photo by H. K. Voris.)

FIXED STAKE NETS, KELONGS, AND FYKE NETS

In the past, these nets were deployed in river mouths and in shallow coastal areas throughout Southeast Asia and northern Australia. They are all stationary, relying on river flow or tidal currents to carry fish and prawns into the nets. Snakes are again a bycatch in these nets. *Stake nets* consist of a net stretched on stakes fixed into the substrate; the fish become trapped in enclosures at one end of the net and are periodically removed by the fishermen. Lights are often deployed around these structures at night to improve the catch.

A *kelong* (Fig. 66) is an offshore platform built for the purpose of fishing. The fishermen deploy nets by wading or swimming in shallow waters or from boats in deeper water. Although marine snakes are an incidental catch at kelongs, extensive samples have been obtained in Malaysia (Voris and Moffet 1981; Voris 1985) and in tropical Australia (Houston and Shine 1994a).

Fyke nets are bag-shaped nets that are held open by hoops and often outfitted with wings and leaders (Fig. 60; these nets described in detail in "Baited Hoop Traps," under "Detecting and Capturing Turtles in Freshwater Habitats," above). They can be linked together in a series and are used to catch fish moving against the current, but they can also be used in lentic waters with dense submergent vegetation. Fyke nets are used in marine and freshwater situations and are sometimes baited. They are often designed for specific species of fish; however, Houston and Shine (1994a) used them successfully to collect *Acrochordus arafurae* in shallow water.

TARGETED HAND COLLECTING

Targeted marine snakes can be hand collected by dipnetting at night with light from ships (Smith 1926; Dunson and Minton 1978). Dipnetting has also been used to capture Yellow-bellied Seasnakes (*Pelamis platurus*) during the day off the west coasts of

FIGURE 66 Kelong, or stake net, near the mouth of the Muar River, Malaysia, 1975. The net was set at high tide and operated on the outgoing tidal river flow. Prawns were the intended catch, but sea snakes such as *Enhydrina schistosa* and *Hydrophis melanosoma* were common in the bycatch. (Photo by H. K. Voris.)

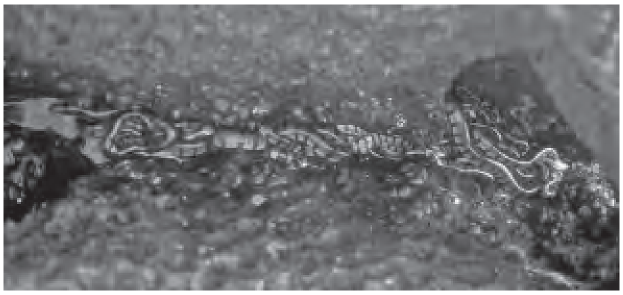

FIGURE 67 A cluster of about 12 Banded Sea Krait (*Laticauda colubrina*) in a rock crevice in the intertidal zone of a small island south of Labuan, Sabah, Malaysia (Borneo). (Photo courtesy of R. B. Stuebing.)

Costa Rica and Panama (Dunson and Ehlert 1971; Kropach 1971) and off the coast of Queensland, Australia (Dunson 1975b).

Sampling and counting marine snakes in clear water while skin and scuba diving has been used effectively in the Philippines (Gorman 1985; Dunson and Minton1978), on the Ashmore (Guinea 1996) and Great Barrier (Heatwole 1975; Burns and Heatwole 1998; Lukoschek et al. 2007) reefs in Australia, and in Taiwan (Tu and Su 1991). In addition, *Acrochordus granulatus* has been sampled by hand by wading in shallow mangrove areas in the Philippines (Gorman 1985; Dunson and Minton 1978).

In general, trawls, stake nets, fyke nets, and other commercial fishing methods are not effective for sampling the amphibious sea kraits (*Laticauda*). Instead, hand collecting in the intertidal and backshore (generally within 50 m of the mean high-tide mark) zones has proven effective for these taxa. Sea kraits are often found on islands (Fig. 67), but they are not restricted to them. Studies have been conducted on *Laticauda* in Taiwan (Tu et al. 1990); the Solomon Islands (McCoy 1985), including Rennell Island (Cogger et al. 1987); Vanuatu (Shine, Reed, Shetty, and Cogger 2002; Shine, Reed, Shetty, LeMaster, and Mason 2002), New Caledonia (Saint Girons 1964), Fiji (Guinea 1994; Shetty and Shine 2002), Andaman Islands (Shetty and Sivasundar 1998), and Malaysian Borneo (Lading et al. 1991; Voris and Voris 1995). In the Philippines, *Laticauda* is hand collected for the exotic leather industry (Punay 1975).

The Oriental-Australasian rear-fanged water snakes in the family Homalopsidae encompass about 37 species in 10 genera (Gyi 1970; Murphy 2007). Ten of these species (*Bitia hydroides, Cantoria annulata, C. violacea, Cerberus australis, Ce. rynchops, Ce.* sp.*, Enhydris bennetti, Fordonia leucobalia, Gerarda prevostiana,* and *Myron richardsonii*) inhabit estuaries and river mouths. Additionally, the mostly freshwater *Homalopsis buccata* can be found in river mouths and estuaries. Although their freshwater relatives have been successfully sampled using funnel traps in Borneo (Voris and Karns 1996) and Thailand (Murphy et al. 1999), the estuarial species have not. Trapping aquatic snakes in intertidal estuarine environments is difficult at best because of the daily tidal exchange and soft substrates. Hand collecting in mangroves, intertidal creeks, and mud flats at low tide or on an incoming tide has proven effective in Peninsular Malaysia (Jayne et al. 1995), Thailand (Voris and Jeffries 1995), New Guinea (see catalogue entries for *Fordonia* from the Museum of Comparative Zoology, Harvard University), and Australia (M. Guinea, pers. comm.). The particular characteristics of the intertidal habitats at a given location determine the practicality of sampling. Although many areas maintain snake populations, few are workable. The two primary factors that determine the workability of a site are physical access and the consistency of the substrate. Handmade mud skis (Fig. 68) are ski-like structures made of wood or other materials that can be used to access areas where walking is impossible, but they too have limitations (Jayne et al. 1995). Their use over changing substrates can be tricky, and becoming stuck in the mud is a very real hazard. In the Pak Phang Peninsula of Thailand, for example, fishermen collected the Southeast Asian Bockadam (*Cerberus rynchops*) on soft mud by using a small board to distribute their weight, which allowed them to scoot along on the surface of very soft mudflats and collect snakes, crabs, and mollusks. In addition, the presence of mature saltwater crocodiles precludes fieldwork in some areas!

Luiselli and Akani (2002) studied an assemblage of snakes inhabiting a mangrove forest in southeastern Nigeria over a period of 4 years. They used hand collecting during random searches, as well as pitfalls, drift fences, cover objects, and basket traps with no-return valves placed with barricades. It is not clear from their description if any of these methods were used in the intertidal zone where traps would be flooded by returning tides. However, of the 19 snake species they collected, only two were aquatic, and they represented only 5 percent of the 160 snakes collected; the other species were arboreal or terrestrial. Thus, it seems unlikely that they were setting traps and drift fences in areas regularly inundated by tides.

In Singapore, Karns et al. (2002) used a boardwalk designed for park visitors as a transect to sample the homalopsid assemblage present in the Pasir Ris Park mangrove forest. They surveyed the area on 12 nights between 7 February and 30 March, with the assistance of from 10 to 14 volunteers. The 200-m boardwalk was divided into 20-m segments and had been previously mapped for microhabitats. This method produced a total of 220 homalopsids representing four species. In addition, two intensive surveys lasting throughout the night were conducted. They demonstrated that the snakes were active throughout the night.

Scorpion Mud Lobster (*Thalassina anomala*) mounds present a unique and difficult microhabitat to sample (Karns et al. 2002; Voris and Murphy 2002). These mounds (Fig. 69) serve as refugia for at least two and possibly four species of homalopsid snakes (*Fordonia leucobalia* and *Gerarda prevosti-*

FIGURE 68 Bruce Jayne using mud skis to search for homalopsid snakes (e.g., *Cerberus rynchops*) on the intertidal mud flats of the Johore Straits at Sungei Buloh, Singapore. The consistency of the mud and the mass and physical condition of the skier are critical factors influencing the effectiveness of this mode of collecting. (Photo by Alan Lim. The *Sunday Straits Times* [March 18, 2001, p. 28]; © Singapore Press Holdings Limited; reprinted with permission.)

FIGURE 69 Excavation of a large Scorpion Mud Lobster (*Thalassina anomala*) mound in a mangrove forest on the west coast of Thailand. The mounds occur in the upper portion of the intertidal zone and are used by the homalopsid snakes *Cerberus rynchops, Fordonia leucobalia*, and *Gerarda prevostiana*. (Photo by J. C. Murphy.)

ana; possibly *Cantoria violacea,* and *Cerberus rynchops*). The mounds may be 1.5 to 2.0 m high and 10 m in diameter. The only way to remove snakes from them physically is by excavation. Collecting the snakes by hand when they emerge to forage seems a more prudent method of obtaining specimens, to avoid long-term damage to the microhabitat.

The few species of New World snake that inhabit coastal marshes and mangroves have been visually observed and hand collected (Hebrard and Lee 1981; Miller and Mushinsky 1990). Xenodontines (family Dipsadidae) of the genus *Tretanorhinus* occur in freshwater and marine habitats of Central and South America and the West Indies and have been caught in minnow traps and by hand (Neill 1965; Schwartz and Henderson 1991).

Other reptilian taxa that enter coastal habitats include skinks, monitors, iguanids, agamids, and a variety of other snakes. These reptiles have been sampled by hand collecting or studied by simple observation. In Sicily, Luiselli et al. (2005) hand collected squamates in a highly degraded coastal marsh and reported that a mammal research team found several terrestrial skinks (*Chalcides chalcides*) in small mammal traps. The Southeast Asian and Pacific Littoral Skink, *Emoia atrocostata* (Scincidae), inhabits mangrove forests, where it forages in tidal pools on crabs, fish, and insects. Alcala and Brown (1967) conducted a population study on this species in the Philippines and collected samples by hand. Ingram (1979) commented on the littoral and mangrove habitats of this species and observed them being displaced upwards from hiding places in mangrove trees by rising tides. The Coastal Snake-eyed Skink (*Cryptoblepharus litoralis*) has been observed foraging on coral reefs at low tide for marine polychaetes and other littoral invertebrates (Horner 1992); Fricke (1970) observed similar behavior in *Cryptoblepharus boutonii cognatus* in Madagascar. Grismer (1994, 2002) described three species of side-blotched lizards (*Uta encantadae, U. lowei,* and *U. tumidarostra*) from islands in the Islas Las Encantadas Archipelago in the Gulf of California, foraging in the intertidal zone for the marine isopod *Ligia occidentalis*.

Varanus indicus, V. prasinus, and *V. semiremex* inhabit the mangroves of Australia and New Guinea (Green and King 1993). *Varanus salvator* is widespread and common in mangroves and freshwater habitats of Southeast Asia and has been trapped using large live traps (Rashid and Diong 1999; S. M. A. Rashid, pers. comm.). The arboreal pitviper *Cryptelytrops purpureomaculatus* species complex, likely including *Trimeresurus cantori* and *T. labialis* (David and Ineich 1999), appears to be restricted to mangrove forests and to have been sampled only by hand. Techniques used on the Galápagos Islands to sample Galápagos Marine Iguana (*Amblyrhynchus cristatus*) were limited to hand collecting, noosing, and visual observations (Butler et al. 2002; Wikelski and Trillmich 1994; Wikelski and Hau 1995).

The hydrophiids, the homalopsids, a few natricids, and dipsadids are the squamates most likely to be encountered in brackish and salt water. The wide array of structural diversity found in marine and estuarial environments requires sampling techniques to be equally diverse. Further, the daily tidal fluctuations, the softness of the substrate, and the complexity of the vegetation make the intertidal habitat particularly challenging. Large crocodiles make sampling estuarine reptiles in northern Australia hazardous. Marine and estuarine studies in the future could benefit greatly from new innovative techniques.

DATA ANALYSIS AND INTERPRETATION

Reptiles from marine and estuarial habitats are most commonly obtained as bycatch of commercial fishing enterprises and consequently are only rarely accompanied by any data. Consequently, species distribution information (geographic, habitat, depth) is most often second hand at best and of limited use. Exceptions to this include instances where investigators are able to accompany fisherman (e.g. Voris 1985) and where scientific expeditions with research-vessel ship time are involved (e.g., Dunson and Ehlert 1971). Thus, the kinds of analyses that are applicable vary a great deal and must be carefully matched to the circumstances. Even when more detailed data are collected by an investigator, it is very often impossible to determine the area from which the sample is being drawn or whether or not a population is closed. Of course, there are important exceptions to this, such as patch reefs, river mouths, isolated sea mounts, and isolated mangrove patches. In many cases, abundances and densities of species can be calculated when units of effort and area or linear distance can be determined (e.g., snakes per square meter of net per hour of deployment; snakes per meter of boardwalk surveyed; snakes per hour of scuba diving at a particular range of depths). These values can then be used for comparisons through time at a particular place or between locations with mostly shared characteristics.