CHAPTER NINE

Marking Reptiles

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Introduction

Why is marking animals useful for biodiversity studies? Although basic inventories provide presence and absence data for a site, whether or not a species persists there depends on the status of the group or population. Analyses of mark-recapture data can provide population information (e.g., on abundance, survivorship, population trends; see Chapter 15, as well as "Permanent Plots," in Chapter 13) that enhances inventory and monitoring data. Likewise, radiotelemetry data can be directly relevant to biodiversity studies, contributing information on habitat preferences and estimating population size and survivorship (see methodology in White and Garrott 1990).

A number of authors have provided comprehensive reviews of techniques used to mark reptiles (e.g., Woodbury 1956; Spellerberg and Prestt 1978; Swingland 1978; Plummer 1979; Fitch 1987; Balazs 1999; Ferner 2007). We recommend that readers consult these publications for an in-depth view of available techniques. In this section, we focus on the techniques that are most commonly used with reptiles as well as on some of the more promising newer techniques. We have attempted to present material sufficient to allow a researcher to implement a technique without consulting original sources. However, we encourage potential users of complex technologies such as radiotelemetry, PIT tagging, and following genetic markers (FitzSimmons et al. 1999) to consult the original literature and confer with investigators experienced in using those methods.

Balazs (1999, pp. 101–102) described successful techniques of marking as "partly science, partly art, and partly guesswork." Ideally, marks should not interfere with an animal's behavior, growth, survival, or probability of recapture. They should be simple and easily applied in a field setting, be physiologically inert, and provide positive, accurate identification to the original researcher who marked the animals, any field assistants, and, especially in the case of long-lived species, future workers. In practice, one or more of these goals may be compromised by the size limitations posed by small species or juveniles of larger species. Marks can be group specific (e.g., age cohort, sex) or individual specific depending on the purpose of the study.

Marks fall into the following general categories: (1) identifying marks already on the animal (e.g., natural color pattern, scars) that can be photographed and subsequently recognized, (2) permanent or temporary tags attached externally, (3) morphological modifications (e.g., toe clipping), (4) color marking with paint or other comparable materials, and (5) telemetric devices. Various factors, both general ones and those specifically applicable to the reptilian group under investigation, should be considered when choosing an appropriate technique. In general, the mass of attachments or implants should not exceed 5 percent of body mass. Another important consideration is animal longevity, which in reptiles ranges from about a year in species experiencing almost complete annual population turnover (e.g., some small lizards) to decades in routinely long-lived turtles. Marks that can be applied to small juveniles and remain readable on large adults years later are unusual. Body shape, which varies considerable among reptile groups, is also important. Tags or transmitters appropriate for box-shaped turtles are unlikely to be suitable for slender, elongate snakes and many lizards. Finally, habitat preferences, behaviors, and other natural history traits can influence the choice of mark type; for example, many species of reptiles burrow in loose soils or sediments, which precludes attachment of external tags or transmitters.

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Identifying Marks and Photographs

The use of patterns or distinguishing marks to identify reptiles is not as common as it is in other groups of vertebrates. McDonald et al. (1996) and McDonald and Dutton (1996) found that the appearance (size, shape, color shade, and pattern) of the pink spot on the top of the head of adult Leatherback Sea Turtles (*Dermochelys coriacea*) was unique for each individual and a highly reliable means of identification. Nevertheless, identification of recaptures with these marks was less than 100 percent accurate, so they used the marks to supplement, rather than replace, flipper tags. It may be that the surface details of turtle scutes, such as patterns of grooves and ridges, will prove adequate for individual recognition. These patterns can be recorded in photographs, photocopies, graphite rubbings, and dental cast molds, which can be taken into the field for subsequent comparisons and identifications (Galbraith and Brooks 1987a).

Exuvia of captive snakes can be saved, and scars or irregularities noted to aid in identification of individuals (Henley 1981). Shine et al. (1988) successfully recognized individual snakes using the variable subcaudal scute formulae along with sex and body size.

In a field study, Stamps (1973) found that she could recognize individuals in a small group of *Anolis aeneus* lizards by their distinctive patterns coupled with various stages of tail regeneration. Carlström and Edelstam (1946) reported the successful use of black-and-white photographs to record unique individual dorsal patterns in *Lacerta vivipara* and throat patterns in *Anguis fragilis*. Because the repeated recaptures required by some marking techniques disrupted natural movement patterns, Rodda et al. (1988) identified individual adult *Iguana iguana* based on general coloration and the natural idiosyncrasies of the scales (e.g., variation in length, attitude, curvature, and tip type) of their dorsal crests. More recently, Sacchi and his colleagues (2010) demonstrated with two species of lizard (*Podarcis muralis* and *Lacerta bilineata*) that recaptured individuals could be identified with close to 100 percent accuracy (98% of recaptures within and 99% percent of captures between years), based on *lepidosis,* or characteristics (e.g., size and shape) and arrangement of scales. The investigators photographed scales in selected areas when the lizards were first captured and digitized them. Digitized photographs of recaptures were matched with photographs on file, using Interactive Individual Identification Systems (I^3S, Classic ver. 2.0) software (see Appendix II). The system works with individuals of any age (juvenile, subadult, adult), independent of color pattern, ornamentation, or lack thereof, and may be applicable to other reptiles, as well.

Permanent and Temporary Tags

A permanent tag is intended to remain on an animal throughout its life or at least for the length of the study, whereas a temporary tag can be as short lived as a few hours or days. Loss is known to occur at various rates for all types of attached or implanted tags. Tag loss should be minimized, but also recorded and included in analyses that assume no loss, such as mark-recapture analyses.

Many different types of external and internal tags, including plastic, metal, string-like spaghetti tags, beads, buttons, spangles, wire, foil, tape, bird bands, aluminum rings, luminescent glass tubes, bells, collars, and rivets, have been used on reptiles with various degrees of success. One of the most promising recent developments in permanent tagging is the *passive integrated transponder* (PIT) tag, a radio-frequency device that transmits a unique numeric or alphanumeric code when inductively powered by a reader placed within a few cm of the tag. A PIT tag allows identification without having to capture and handle the animal. The biologically inert, reusable, glass-encapsulated tag contains no battery (hence the term "passive") and has an estimated life span of up to 75 y. The most common frequency currently used for reptiles is 125 kHz. PIT tags circumvent identification problems sometimes encountered when using morphological modifications by providing a positively identifiable code that is readable by anyone. The main disadvantages of PIT tags are the high costs of both tags (ca. US$5 ea.) and reader (ca. US$1,500), a high rate of tag loss, and in some cases, movement of tags. In addition, PIT tags are inappropriate for studies that rely on tag reportage from the general public. Tag injection sites should be chosen to provide practical scanner access and to minimize chances of tag breakage from normal locomotor movements and collisions.

Radioisotopes have been used as tags to mark and track small turtles, lizards, and snakes (Ferner 2007). However, radioisotope techniques are not commonly used in reptiles because of limited detection distance, inability to discriminate among individuals, potential danger to study animals, high cost, legal restrictions on isotope use, and the recent development of more effective remote sensing techniques such as miniature radiotransmitters and PIT tags.

Tagging Different Reptile Groups

Turtles

Various types of metal and plastic tags have been attached to hard-shelled turtles (Plummer 1979; Ferner 2007). The preferred site is the posterior carapace, to which tags can be attached with screws, glue, or wires running through holes drilled in the shell. Tags can be numbered or colored differently for remote identification (Loncke and Obbard 1977; Buhlmann and Vaughan 1991). Metal tags attached to *Chelydra serpentina* provided identification from up to 40 m through a telescope and remained in place for at least 3 years with no loss (Loncke and Obbard 1977). Because hatchling turtles have relatively soft shells, attaching a tag can pose a problem. Layfield et al. (1988) found that metal wire rings passed through holes punched in the posterior marginal scutes in hatchling turtles had high retention rates. Internal wire tags inserted into the flipper of hatchling or larger turtles can be detected by X-ray equipment or magnetized for later detection by a magnetometer (Balazs 1999). Some tags pose a hazard to turtles, as they tend to get caught on fish nets and discarded fishing line (Graham 1986). Metal and plastic tags are placed on the proximal trailing edge of a front flipper of sea turtles despite low retention rates in all species (Balazs 1999). Tag material affects tag life and retention rates. *Dermochelys* on St. Croix, for example, retained only 16 percent of monel (nickel-copper alloy) tags beyond 4 years, but tags made of other materials were lost much sooner (McDonald and Dutton 1996). Compared to monel, titanium is less affected by corrosion, but unfortunately it is colonized by barnacles, which increases drag, tearing of tissues, and eventual tag loss (Parmenter 1993). Bellini et al. (2001) found that inconel (a nickel-iron-chromium alloy) tags had a much higher retention rate during a 5-year study of *Eretmochelys imbricata*. Balazs (1999) provided an excellent practical guide to tagging sea turtles.

Tags should be loosely attached to the carapace of softshells because of the tendency of the fleshy shell to become necrotic at the point of any firm attachment of a foreign object. Cattle ear tags have been attached to the rear carapacial edge in many hardshelled species by first drilling a hole in one of the marginal scutes. For *Carettochelys,* which lacks marginal scutes, the hole must be drilled into the suture line between the marginal bones to avoid necrosis and subsequent tag loss. Tags so attached remain in place for at least 4 years (S. Doody, pers. comm.).

Although internal PIT tags have been used in relatively few freshwater (Buhlmann and Tuberville 1998) and sea (Fontaine et al., 1987; Parmenter 1993; McDonald and Dutton 1996; Balazs 1999) turtles, we highly recommend them, both for ecological studies and for tracking commercial use. PIT tags can be especially practical for tagging Leatherback Sea Turtles, which lose external tags at an extremely high rate (Balazs 1999). Retention of PIT tags appears to be relatively high in all species on which they have been used. Apparent tag loss from large-size species may actually reflect an inability to detect the tag because the tag and reader are too far apart or because individuals doing the reading have not been properly trained (McDonald and Dutton 1996). Buhlmann and Tuberville (1998) recommended the use of PIT tags on small freshwater turtles but not on hatchlings. Although recommendation of standard PIT tag implantation sites may be premature, the body cavity in the anterior inguinal region parallel to the bridge of the shell appears to be a good site for freshwater turtles (Buhlmann and Tuberville 1998), and subcutaneous or intramuscular locations in the shoulder appear appropriate for sea turtles. Tags in these regions provide reliable readings and move very little (Parmenter 1993; McDonald and Dutton 1996). PIT tags should not be implanted intraperitoneally in species of turtles that get to be large, because tag movement in the body cavity can place the tag beyond the detection distance of the reader. We do not recommend placing tags in predrilled holes in the shell, because of relatively high rates of shell breakage and tag loss.

A variety of devices have been temporarily attached to the posterior portion of the carapace of turtles to provide short-term spatial and behavioral information. Thread trailing involves following a continuous thread that is pulled from a spool attached to the carapace or from a trailing device pulled behind the turtle (Reagan 1974; Wilson 1994; Claussen et al. 1997). To locate nest sites of female *Chrysemys picta,* J. Congdon (pers. comm.) temporarily attached transmitters to their posterior carapaces with duct tape. Darkened tin foil has been molded to the back of hatchling *Malaclemys terrapin* for redetection with a metal detector inside artificial field enclosures (A. Tucker, unpubl. data). In comparatively obstruction-free waters, stiff lines or wires can be attached to the posterior carapacial edge to tow highly visible, streamlined flotation tags. Such tags should be fabricated with a "weak link" so that they will detach from the carapace easily if they become entangled. Sea turtles in the open ocean may tow helium-filled balloons to increase long-distance visibility obscured by the curvature of the earth.

Lizards

A variety of materials have been used for external tags of lizards. Tags generally are easier to "read" in the field than morphological modifications (e.g., toe clipping) and can be used in conjunction with more permanent markings. Minnich and Shoemaker (1970) marked *Dipsosaurus dorsalis* with colored Mystik cloth tape that they placed in various color combinations of bands around the base of the tail. Deavers (1972) tagged *Uma notata* with small pieces of foil attached to a 30-cm piece of light string, which was tied around the lower abdomen. The tag allowed him to measure the burial depth of the lizards in the sand at night. Similarly, Judd (1975) attached a square piece of aluminum foil, 5 cm on a side, to a 1-m length of red thread to locate buried *Holbrookia propinqua* for body temperature readings.

Rao and Rajabai (1972) tagged agamid lizards (*Sitana ponticeriana* and *Calotes nemoricola*) with colored aluminum rings of various sizes. These rings were placed around the thigh and caused no apparent problem. In a field study of *Uma inornata,* Fisher and Muth (1989) sewed a series of small (2.0 × 2.5 mm) plastic jewelry beads to the base of the tail with surgical steel monofilament. Henderson (1974) tagged *Iguana iguana* by tying small "jingle bells" around their necks with fishing line! Zwickel and Allison (1983) applied pressure sensitive rip-stop nylon tape to the backs of *Emoia physicae* after washing the skin with 95-percent alcohol. The 5- × 10-mm pieces of tape were then color-coded with acrylic paint. Colored plastic bird bands glued to the tails of *Aspidoscelis sexlineata* lasted much longer than field marks painted on the tail (Paulissen 1986).

Clark and Gillingham (1984) made nocturnal observations of *Anolis* sp. by gluing small capillary tubes filled with a phospholuminescent liquid to the lizard's dorsum at dusk. The glowing markers, visible up to 30 m away, lasted up to 6 hours and were sloughed off by the lizards within 24 h with no apparent harm.

Snakes

External tags (e.g., jaw tags, plastic buttons, beads, spangles) have been used on snakes only rarely (Spellerberg and Prestt 1978; Fitch 1987; Ferner 2007); we do not recommend their use, because of the potential problems of entanglement in vegetation and limited access to narrow burrows for an otherwise streamlined body.

Although PIT tags show promise as an ideal marking system for snakes (Camper and Dixon 1988; Keck 1994b; Jemison et al. 1995), tag movement and low retention rate may be of concern. Deep intraperitoneal rather than superficial subcutaneous injection may reduce tag loss (Jemison et al. 1995). All tags that Roark and Dorcas (2000) injected intraperitoneally in the mid-body region of subadult *Pantherophis guttatus* were retained, whereas more than 50 percent of the tags injected in the neck region moved posteriorly and were expelled in the feces. PIT tags can be successfully introduced to snakes via implanted prey, but retention by the snakes from ingestion to defecation may be only 2 weeks (MacGregor and Reinert 2001).

Crocodilians

PIT tags have been used successfully to mark hatchling caimans (Dixon and Yanosky 1993), although their use on juvenile or adult crocodilians has not been extensively evaluated. Tags were injected into the base of the tail just behind the insertion of the hind limb. PIT tags should not be injected intraperitoneally, because of possible migration in the body cavity, which, in these large animals, could move the tag out of detection range of the reader. Dixon and Yanosky (1993) regarded PIT tagging as superior to most other systems of marking caimans.

The large projecting scutes of crocodilians provide plenty of opportunities for attaching tags. Bayliss (1987), for example, inserted harpoon tags into the neck scutes of subadult and adult Australian crocodilians. These numbered tags, large enough to be read from a distance, were held in place with harpoon-like barbs. Tags have also been attached to foot webbing. These large reptiles have also been fitted with neck collars, which are commonly used to mark large mammals (Brandt 1991).

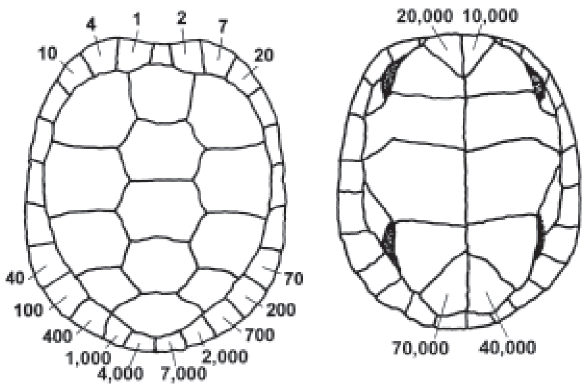

FIGURE 41 Ernst et al.'s (1974) numerical coding system for hardshelled turtles as exemplified by Pond Sliders (*Trachemys scripta*). (Left) Carapace with numerical code for each marginal scute. (Right) Plastron with numerical code for each gular and anal scute. A unique specimen number is obtained by adding the numerical values assigned to each notched scute. For example, *T. scripta* No. 1474 would have notches in marginal scutes nos. 1000, 400, 70, and 4. Modifications of this system may be necessary to accommodate turtles with only 11 marginals on a side (e.g., kinosternids).

Morphological Modifications

Modifying the morphology of the study animal is an inexpensive and rapid method of marking large numbers of animals in the field. However, application techniques of individual researchers and healing patterns of individual animals vary, so positive identification may be difficult, especially for field technicians lacking experience with the system and the study species.

Turtles

The hard upper shells of freshwater and terrestrial turtles have been subjected to the most kinds of marking techniques. The marginal scutes on the carapacial edge have been cut, sawed, filed, ground, and drilled in various coding schemes to provide unique identification marks. Unfortunately, the carapacial edge is also particularly subject to natural injury from a variety of sources (e.g., predators). Such injuries can obscure identification marks already present or serve as an additional identification mark, if inflicted before marking.

Cagle (1939) assigned a number to each marginal scute from anterior to posterior on each side of the carapace so that he could designate the scutes that he notched. He used a comma to separate marginals on the same side and a hyphen to separate the left and right sides. Thus, in turtle number 2,9-1,3, he marked marginals 2 and 9 on the left side and 1 and 3 on the right. With up to four notches, more than 2,000 different turtles can be numbered uniquely with Cagle's system. In a simpler system providing more available numbers, scutes are modified for sequential numbering (e.g., Ernst et al. 1974; Fig. 41). The marginals at the bridge or juncture of the carapace and plastron (usually the 4th–7th marginals) are not used by most researchers. However, bridge scutes can be used like any other scute, provided that marks are applied with a triangular file (A. Tucker, pers. comm.).

J. Congdon (pers. comm.) used a simple sequential system employing letters, rather than numbers, to mark more than 14,000 turtles of several species. He lettered the marginals from A to M (includes turtles with 13 marginals), anterior to posterior, on the turtle's right side (A–K in kinosternids) and N to Z on the left (N–X for kinosternids). Marginals D to F on the right and R to T on the left are not used. From 2 to 4 scales are notched and read sequentially (e.g., AB, CJ, HIJ, IKWX). This simplified scheme can be applied uniformly to turtles with different numbers of marginals; one only has to remember the alphabet and that the first marginal scale on the right is letter A and on the left, letter N. Cogdon consistently recognized the more than 40,000 individuals he recaptured over 26 y. This coding system also reduced the frequency with which new or part-time participants in a research project misread the identifications (J. Congdon, pers. comm.).

Softshell turtles (Trionychidae), lacking epidermal scutes and dermal bone at the carapacial edge, can be marked by removing small V-shaped pieces of carapace with a sharp knife or punching holes in the carapace with a paper punch (Doody and Tamplin 1992). The V-shaped or circular marks quickly fill out to the carapacial edge as healing progresses but persist as distinct whitish scars best seen from the ventral surface. Coding is more difficult because of the lack of discrete marking sites, that is, individual scutes. One softshell coding system involves numbering positions 1 through 12 as if a clock face were superimposed on a dorsal, posterior view of the carapace (Plummer 2008). Using a combination of from 1 to 5 carapacial cuts in combination with toe clips, Plummer (1977; unpubl. data) marked more than 1,000 *Apalone mutica* and *A. spinifera*.

Hatchling and young sea turtles have been group-marked by surgically exchanging small pieces of tissue between the carapace and plastron. These "living tag" tissue graphs produce contrasting pigment patterns that are retained by older turtles (Balazs 1999).

Lizards

Toe clipping is by far the technique most commonly used to mark lizards for identification. Tinkle (1967) developed a numbering system for *Uta stansburiana* that involved clipping up to four toes, but no more than two per foot and never adjacent ones. The removal of toes 4, 8, and 20, for example, would give the lizard a code number of 4-8-20 (Fig. 42). Medica et al. (1971) developed a different numbering system (Fig. 42) similar to the one often used for salamanders and frogs. In that system, at least one toe from each foot is cut to eliminate the problem of a lizard having lost a digit(s) accidentally being mistaken for a marked animal. Woodbury (1956) suggested lettering the feet (A–D), numbering the toes (1–5), and using combinations of those designations along with the sex of an individual for its identification code. A male with the first

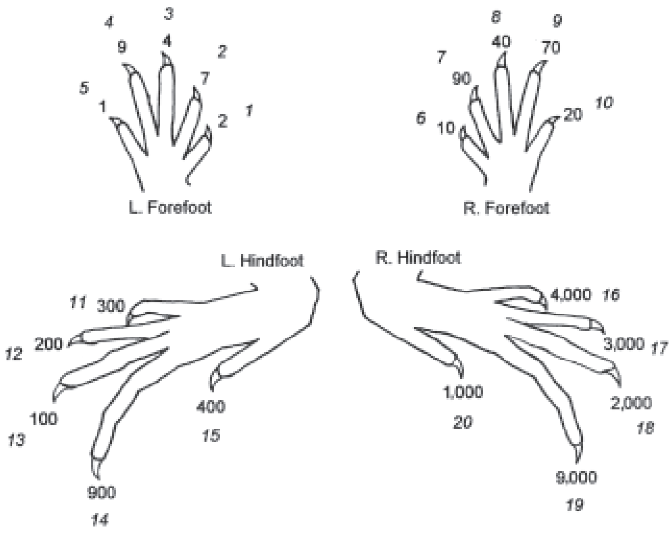

FIGURE 42 Dorsal views of lizards with numbered toes. The outer numbers (italicized) represent Tinkle's (1967) system for numbering lizard toes. The inner numbers represent Medica et al.'s (1971) system for numbering lizard toes. A unique specimen number is obtained by adding the numerical values assigned to each clipped toe.

toe of his left front foot and the second toe of his right hind foot clipped would be A1-D2-Male. In his alphanumeric code, Waichman (1992) also gave each foot a letter and numbered the toes on each limb 1 through 5. Using this code and clipping up to three toes, but no more than two per foot, 1,310 lizards can be individually marked.

Woodbury (1956) suggested that toe clipping might have a harmful effect on lizards, but this does not appear to be the case. Australian skinks loose toes naturally at a relatively high rate with no major effect on survivorship (Hudson 1996), which indicates that toe clipping may be an appropriate marking technique. Dodd (1993b) found that toe clipping had no immediate or long- term effects on sprint performance of *Aspidoscelis sexlineata* when only two toes were clipped per individual. Finally, the sprint speed of *Sceloporus merriami* was not correlated with the number (up to four) of toes clipped per individual (Huey et al. 1990).

Snakes

Early on snakes were marked with tattoos, hot brands, and freeze brands (Spellerberg and Prestt 1978; Fitch 1987; Ferner 2007), which are still used occasionally (e.g., Burns and Heatwole 1998). Nowadays, however, most researchers mark individual snakes by clipping either subcaudal or ventral scales. Brown and Parker (1976b) devised a simple and practical serially numbered system of clipping ventral scales just anterior to the vent (Fig. 43). Clipping ventral scales may be preferable to clipping subcaudals because ventrals are larger, easier to clip, and remain even if the tail breaks; clipping ventrals may, however, be more traumatic to the snake (Fitch 1987). Clipped scales, of whatever type, need to be periodically reclipped, as the clips often become obscured by regeneration after several years, which hinders indentification (Fitch 1987).

To clip ventrals, the tips of small, sharp-pointed scissors are inserted under the posterior edge of the scute to be marked, which is then cut in an anterior direction over its entire length,

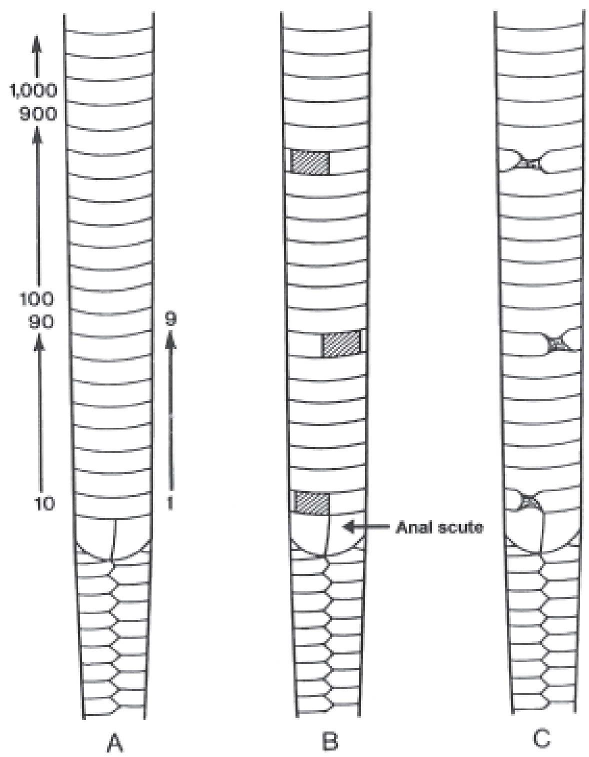

FIGURE 43 Ventral scale clipping system for marking snakes. Ventral view of posterior body of a North American Racer (*Coluber constrictor*). (A) Enumeration of ventrals proceeds anteriorly from the anal scute: series of scales indicating 10s, 100s, and 1,000s on the observer's left; scales indicating units on the observer's right. (B) Snake freshly marked with number 718. (C) Snake 718 three years after initial marking, showing appearance of scars. (From Brown and Parker 1976b; © *Jounal of Herpetology,* redrawn with permission.)

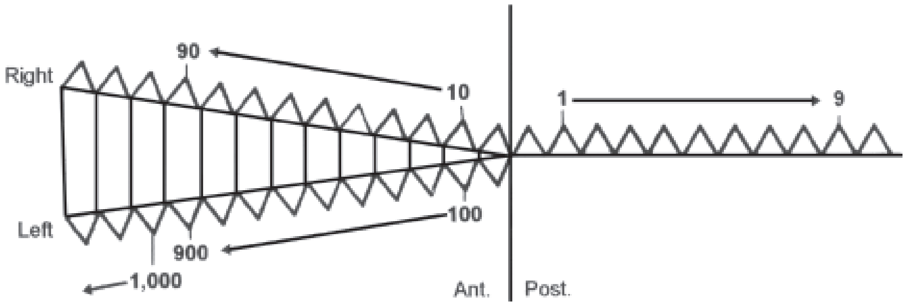

FIGURE 44 Simplified numbering scheme for marking crocodilians. The single row of enlarged dorsal median scales divides into two dorsolateral rows anteriorly. The diagram presents a lateral view of the posterior portion of the tail and a dorsal view more anteriorly. Immediately anterior and posterior to the division point are the "0" scales from which radiate the 1s, 10s, and 100s. Variations are used for alligators, caimans, and gavials (A. Tucker, pers. comm.).

back to front. Each mark requires two longitudinal cuts, one to the side and one toward the middle of the scale, roughly one-half the width of the scale apart. These cuts are then joined anteriorly with a transverse cut, and the isolated rectangular block of tissue is removed (Fig. 43). A small piece of scute must remain laterally so that the scute can be counted later, after healing. The cut also must be deep enough to remove the entire dermis; otherwise ,regeneration may obliterate the mark. In some snakes the ventral scalation may be anomalous, for example, with a scute duplicated on one side (e.g., Plummer 1980). Anomalous scute patterns and scute injuries must be incorporated into any scute-marking scheme.

Crocodilians

Various workers have notched or cut dorsal crest and tail scutes on crocodilians in several accepted marking schemes, but no systematic or standardized marking system has been published as has been done commonly for turtles, lizards, and snakes. This lack of standardization probably reflects the large number of scutes available for marking and the different marking needs of commercial farms, wildlife management agencies, and investigators carrying out population studies (A. Tucker, pers. comm.). A proposed scheme for marking dorsal scutes is shown in Figure 44.

Color Marking

A variety of temporary color marks (e.g., numbers, letters, color codes) have been applied to reptiles to facilitate visual recognition at a distance. Small amounts of quick-drying, nontoxic paints applied with a brush, spray can, or paint pen/marker work well and have been used on turtles (e.g., Auth 1975), lizards (e.g., Medica et al. 1971), snakes (e.g., Henderson and Winstel 1995), and crocodilians (e.g., Seebacher and Grigg 1997). Temporary paint marks for some species may be applied without capture (e.g., Passek and Collver 2001). Xylene-based paint pens should be avoided for most species; xylene is toxic and can affect behavior and survival (Boone and Larue 1999; Quinn et al. 2001). Because color marks are temporary, they are usually used in conjunction with more permanent techniques. In *Opheodrys,* paint marks began flaking off after 2 to 3 days and were completely gone after about 2 weeks (Plummer 1981). Similarly, underwater-curing, epoxy-paint marks on *Caretta* were visible for about 14 days (Tucker et al. 1996). Penney et al. (2001) successfully injected visible implant elastomer (VIE) to mark *Plestiodon reynoldsi*. Developed for marking migratory fish, the liquid elastomer is injected subcutaneously and hardens into a flexible mark within a few hours. In an extensive study of *Sceloporus jarrovii,* Simon and Bissinger (1983) found no differences in survivorship between animals with conspicuous or more cryptic color makings. Similarly, mortality did not differ significantly between individuals of *Sceloporus undulatus* marked with a spot of paint at the base of the tail and those left unmarked (Jones and Ferguson 1980).

Color marks on hard body parts persist the longest. The turtle carapace is an obvious place to paint identification numbers and letters. Paint should be applied sparingly to small turtles with rapidly growing unossified carapaces, because the paint may hinder growth and cause disfigurement. Although rattlesnake rattles have been variously marked with tags, beads, disks, spangles, and so forth, color marking has become more or less standard practice. Color marking allows for quick recognition of marked animals at a distance and also provides data on shedding frequency (Brown et al. 1984). Paint can last up to about 8 y on individual rattle segments of *Crotalus horridus* (W. S. Brown, pers. comm.).

An unusual form of short-term color marking is the use of powdered fluorescent pigments. The fine powder readily adheres to a reptile's body, and as the animal moves through its habitat, it leaves powder traces that can be detected with a portable UV light. This technique has been used to track small lizards and turtles (e.g., Fellers and Drost 1989; Butler and Graham 1993; Stark and Fox 2000), and in combination with thread trailing, greatly facilitated locating tortoise nests (Keller 1993).

Radiotelemetry

Radio-frequency transmitters are usually used in conjunction with more permanent marking techniques such as scute marks or PIT tags. With the notable exception of sea turtles, few reptiles are large and mobile enough to require triangulation or satellite telemetry. Indeed, a common problem in reptilian telemetry is how to pinpoint the location of small animals at very close range. Using a receiver with an "attenuator function," which maintains signal directionality at very close ranges, greatly facilitates this task. Microprocessor dataloggers have been attached or implanted in various reptiles and are usually used in conjunction with radiotelemetry. A disadvantage of most dataloggers is that the logger must be recovered for data retrieval. The marine units used on sea turtles, however, are exceptions; they are capable of relaying data via satellite from a datalogger mounted on the turtle to a computer in a researcher's lab.

Transmitters and other telemetry equipment are available from a number of manufacturers that are usually listed with contact information on websites that compile links to biotelemetry information. Several such sites are listed in Appendix II. A visit to any of these sites quickly reveals an overwhelming number of biotelemetry uses and manufacturers and can easily confuse one not familiar with applications specific to reptiles. Although common elements exist among applications, telemetry systems, especially transmitters, usually are configured to meet each user's unique needs. This specificity is especially true for reptiles, which as a group vary greatly in morphology and habitat preferences. Researchers new to telemetric applications in reptiles should survey articles published in major herpetological journals (e.g., *Copeia, Herpetologica, Journal of Herpetology*) and identify sources of telemetry equipment. Various sources are also listed in Appendix II. In addition, we recommend that new users consult both the primary literature and established researchers who use telemetry on reptiles for accepted practices and advice on using this technique.

Turtles

Despite strong attenuation of radio-frequency signals under water, VHF radio-frequency transmitters have been commonly used on aquatic and marine, as well as terrestrial, turtles. Low-frequency (sonic) transmitters designed for fish transmit well under water and have been used on a variety of marine turtle species (Eckert 1995, 1999) but only on one freshwater turtle species (Moll and Legler 1971). The Argos satellite system, a worldwide tracking and environmental monitoring system, has been widely used to track marine turtles globally. Platform transmitter terminals, mounted on turtles, transmit various kinds of data (e.g., latitude and longitude, temperature, date, time, number and duration of dives) to an orbiting satellite (Renaud et al. 1993; Renaud 1995; Beavers and Cassano 1996), which picks up the signals and relays them in real-time to over 50 ground stations located at points around the globe. Data are then sent to one of two Argos centers, which processes the data and delivers the information directly to Argos users' desktops around the world.

Boarman, Goodlett et al. (1998) reviewed the methods of transmitter attachment in 113 radiotracking studies of turtles. They grouped attachment methods into six categories: (1) adhesives (e.g., dental acrylic, epoxy, silicone sealant), (2) harnesses, (3) wire, screws, bolts, cable, nylon ties, or monofilament line passed through holes drilled in the carapace, (4) surgical implantation, (5) sewing, and (6) taping. Transmitters should be flat and closely conform to the carapace to prevent entanglement in filamentous algae or other vegetation and should be placed away from the peak of the carapace to prevent obstruction of narrow or low burrows.

Transmitters should be loosely attached to the fleshy, highly vascular shells of softshells (Trionychidae) to minimize shell necrosis and subsequent transmitter loss. Plummer and Burnley (1997) and Plummer et al. (1997) attached transmitters to the posterior carapace of softshells with a single stainless-steel wire punched through the carapace and held loosely in place on the underside with a plastic button. The cigar-shaped transmitter was loose enough to pivot freely. Both transmitters and dataloggers have been implanted into the body cavities of softshells (Plummer and Burnley 1997; MVP, unpubl. data).

Transmitter trailing devices consisting of a trailing transmitter alone (J. Demuth, unpubl. data) or a transmitter in combination with a spool of thread (Lemkau 1970) and a datalogger (Plummer 2003) have been commonly used on turtles of the genus *Terrapene.* Trailer packages should be streamlined and attached close to the carapace so as to pivot freely.

Lizards

Transmitter packages used in early telemetry studies of lizards, such as *Iguana iguana* (Montgomery et al. 1973) and *Sceloporus occidentalis* (McGinnis 1967), were considerably larger and heavier than those available today. However, attaching transmitters to the backs of small lizards still remains a challenge. Richmond (1998) fabricated a harness for small lizard species using rubber from a bicycle inner tube. The backpack harness used by Ussher (1999) on tuatara (*Sphenodon* sp.) held transmitters weighing less than 4 g. The harness consisted of a 30-×20-mm pad of porous polypropylene webbing with two 4-mm-wide polyester straps and two lengths of 13-mm-wide polyester elastic braid. The straps attached the transmitter to the pad. The braid, one length passing around the neck of the lizard and the other around its body behind the forelimbs, attached the pad to the animal. The harnesses were reliable and lasted up to 5 months. They also proved safe for the lizard, if correctly fitted to minimize or prevent abrasion. Fisher and Muth (1995) made a similar backpack for attaching radio transmitters to *Phrynosoma mcallii,* using polypropylene tape and clear polyurethane elastic, which are available at most fabric stores. Small radio transmitters can also be surgically implanted into lizards. Wang and Adolph (1995) found that these implants did not alter the thermoregulatory patterns of free-ranging Western Fence Lizards (*Sceloporus occidentalis*).

Snakes

The refinement of miniature implantable transmitter packages has revolutionized ecological research on snakes in recent years (Shine and Bonnet 2000). Transmitters are usually surgically implanted intraperitoneally, or in larger-size species, subcutaneously; the antenna is implanted subcutaneously. Detailed descriptions of surgical techniques can be found in Reinert and Cundall (1982), Weatherhead and Anderka (1984), and Reinert (1992). Transmitter shape may not be critical in large or heavy-bodied species such as *Crotalus* and many boids, but in many colubrids, especially juveniles, transmitter size and shape may be limiting. Elongate, flattened transmitter packages are preferable to short, cylindrical designs. Most transmitter manufacturers will work with researchers to provide needed shapes. Some snake researchers purchase unpotted transmitters without batteries and shape the final package themselves. Temperature dataloggers have been similarly implanted in heavy-bodied *Crotalus* (M. Dorcas, unpubl. data). Researchers should avoid implanting transmitters late in the activity season because cool weather can hinder healing of the surgical wound (Rudolph et al. 1998). They should also monitor the effects of the surgery on snake behavior and physiology (Charland 1991; Lutterschmidt and Rayburn 1993).

Ciofi and Chelazzi (1991) sewed external transmitters to the backs of individual *Coluber constrictor flaviventris,* but their technique has not been used widely. Transmitters may be force-fed to snakes for short-term monitoring. The transmitter is eventually passed in the feces by normal peristaltic movements but will be retained if a restriction thread is tied around the body in back of the transmitter (Fitch 1987). However, we strongly recommend against the use of restriction bands to increase the time a transmitter is retained. Harlow and Shine (1988), Shine (1991a), and Steve Beaupre (pers. comm.) have enticed dangerously venomous elapids and viperids to voluntarily ingest mice containing transmitters, and Burns and Heatwole (1998) enticed the sea snake *Aipysurus laevis* to ingest fish containing sonic transmitters. However, having a transmitter in the digestive tract may alter normal snake behavior (Fitch 1987; Lutterschmidt and Reinert 1990).

Harmonic direction finders have been used to track two snake species (Webb and Shine 1997; Engelstoft et al. 1999). These novel devices are passive, like PIT tags, and thus do not require power sources. Consequently, they can be exceedingly small (0.5 mg). Harmonic direction finder technology holds promise for tracking snakes (Webb and Shine 1997; Engelstoft et al. 1999) and lizards too small for radio transmitters, whose lower size limit is determined by the battery. Current disadvantages of harmonic direction finders include short detection distance, lack of individual recognition, false signals, tags not available commercially, and the high cost of the transceiver (ca. US$6,000; Engelstoft et al. 1999).

Crocodilians

The large size of crocodilians and their projecting dorsal scutes provide various opportunities for implanting and attaching transmitters and dataloggers. Transmitters have been attached externally in a variety of locations, including on neck collars (Rootes and Chabreck 1993b) and on the dorsal caudal scutes (Muñoz and Thorbjarnarson 2000). For short-term tracking of location and body temperature, *Paleosuchus* and *Crocodylus porosus* can be induced to swallow prey carcasses with transmitters inside (Magnusson and Lima 1991; Grigg and Seebacher 2001). For additional information on the use of radiotransmitters with crocodilians, see “Radiotelemetry,” under “Swamp-Dwelling Crocodilians,” in Chapter 11.

Cautions and Recommendations

1. Shell notching, toe clipping, and scale clipping are reliable and inexpensive methods for marking reptiles. However, these techniques require skill, and investigators should practice them before employing them in the field.
2. Newer techniques for marking should be tested in the laboratory but then used in the field only in conjunction with proven methods until they are deemed accurate and reliable.
3. All tags to be applied externally should be tested for possible interference with locomotion, mating, and foraging. Tags that snag vegetation may be a problem for species inhabiting lush vegetation in both terrestrial and aquatic environments. We do not generally recommend external tags for snakes, burrowing or legless lizards, or amphisbaenians.
4. Color marking, used in addition to more permanent marks, can facilitate field identification and minimize the need for recapture.
5. External tags, transmitters, or color marks may make animals more conspicuous to predators and to conspecifics.
6. Tag loss is an important issue in mark-recapture studies because it violates a primary assumption of population estimation methods. Rates of tag loss should be recorded and included in analyses that assume no loss.
7. PIT tags can be an excellent technique for marking providing positive identifications for many species of reptiles. Before employing pit tags, however, investigators should carry out preliminary work on the species in question, especially snake species, to determine whether the tags will be retained at a useful rate and whether or not they will affect growth and subsequent population dynamics. PIT tags should not be injected into the body cavity of large individuals because of possible tag movement beyond the detection distance of the reader. Also, we do not recommend placing tags in pre-drilled holes in the turtle shell.
8. Telemetry is an extremely valuable tool for obtaining large amounts of data on relatively few individuals; however, it is not without problems. We caution new telemetry users that the “art” of finding animals in the field can be more difficult than might first appear. Thus, one should allow sufficient time to get past the learning stage before actual data collection begins.
9. Investigators should take precautions when employing marking techniques that require contact with blood or other body fluids to prevent the spread of disease among animals. Application tools should be disinfected after each animal is marked. Balazs (1999) recommended that investigators employ two sets of tagging equipment, one for healthy animals and another for obviously diseased animals.

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