

STANDARD METHODS FOR MEASURING BIOLOGICAL DIVERSITY: REPTILES

Chap. 4, pt. 5.

Automated Data Acquisition

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Introduction

Data quantifying the relationship between changes in environmental variables and changes in reptile activity levels and/or physiological states (e.g., temperature) can be used to optimize sampling procedures for survey and monitoring programs and to interpret changes in reptile population levels (Peterson and Dorcas 1992, 1994). Our objective in this chapter is to describe the use of automated devices to measure variation in the physical environment as well as changes in the activity levels of reptiles.

We will focus on continuous, automated sampling systems, rather than single, manual measurements, because such systems make it possible to measure a variety of variables accurately at one or more sites. Being able to sample regularly over intervals of different lengths is important because many factors vary through time. Environmental attributes important to reptiles (e.g., temperature) can change dramatically over just a few hours as well as over days, months, or seasons (Peterson et al. 1993). We will discuss how to monitor reptiles' environments automatically using dataloggers, environmental sensors, and physical models. We will also discuss ways to (1) monitor reptile activity using automated radiotelemetry, (2) monitor body temperatures of reptiles with attached or implanted dataloggers, (3) monitor global positioning systems (GPS) attached to animals, (4) automate passive integrated transponder (PIT tag) systems, and (5) employ automated photographic and video systems.

We obtained some of the information we report concerning dataloggers and environmental sensors from Percy et al. (1989), Campbell (1990), and Tanner (1990), which readers may wish to consult. Throughout the text we cite the names of manufacturers or retailers, especially for equipment and materials that we have used. However, our experience with different techniques and different types and brands of equipment is limited; thus, the listing or omission of a particular vendor does not indicate either our endorsement or rejection. Furthermore, equipment is evolving rapidly, and many of our specific comments will soon be out of date.

Dataloggers

A datalogger is an instrument that records and stores data collected by one or more sensors. Dataloggers are generally programmed by some sort of computer (e.g., notebook or laptop). They operate autonomously, and the data they collect are downloaded to a computer after some prescribed period. All dataloggers work essentially the same way, by measuring voltages produced by sensors (i.e., transducers such as thermistors). Most dataloggers are able to convert raw voltages into the unit of interest (e.g., volts into degrees). Some dataloggers can also be used to control instruments, turning a piece of equipment on and off at specified intervals. Dataloggers are either single- or multi-channeled. Single-channel dataloggers receive input from only one sensor, and multi-channel dataloggers, from two or more sensors.

MULTICHANNEL DATALOGGERS

Within the past 25 years, the task of gathering continuous data has been greatly facilitated by the development of dataloggers suitable for use in the field. The distinguishing characteristics of field dataloggers include portability, battery power, programmability, and the ability to read

inputs from several types of sensors at user selected intervals (Campbell 1990). Dataloggers have numerous advantages over devices such as mechanical recorders and strip chart recorders, including a wider operating temperature range, increased sensor compatibility, higher accuracy, greater data storage capacity, and much easier transfer of data to computers for analysis (Pearcy et al. 1989).

Factors to consider when selecting a multichannel datalogger include cost, reliability, the range of operating conditions (temperature and humidity), accuracy, resolution, number of channels, sensor compatibility, processing power, data storage and retrieval options, and power requirements (Tanner 1990). Costs range from approximately \$60 to over \$5000 US. Powerful, versatile systems, capable of measuring most sensors, are available for less than \$1700 (including the interface and software for downloading data). Features to look for in this price range include 12-bit or greater resolution, the ability to measure microvolts (e.g., thermocouples), switch or pulse-counting capability (for cup anemometers and tipping-bucket rain gauges), the ability to provide excitation voltages (for thermistors and electrical resistance humidity sensors), and digital outputs for controlling devices such as tape recorders and radiotelemetry systems. A more expensive datalogger, capable of resolving nanovolts, is required for measurements of some variables (e.g., soil-water potentials using thermocouple psychrometers).

If funds for purchasing a datalogger are not available, investigators should try to borrow one or to use data already being collected with a datalogger at or near his or her study site. It may even be possible to add sensors to a multichannel system presently operating at the site. As costs decline and dataloggers are becoming more affordable, many universities, field stations, government agencies, parks, and similar institutions have machines available for use by

researchers. Investigators should learn how to deploy and program their dataloggers. Becoming comfortable with the more powerful and flexible systems (e.g., Campbell Scientific), may require considerable time (i.e., at least several days or weeks). Investigators can minimize learning time by working with someone already familiar with the equipment. Some manufacturers offer training sessions that may be helpful for less technologically savvy users. Many dataloggers now come with user-friendly software that allows even the novice to begin using the equipment after minimal learning time. Onset Computer Corporation manufactures a relatively inexpensive weather station that is considerably easier to use than the systems produced by Campbell Scientific. In general, an entire Onset weather station (up to 15 sensors) can be set up in an afternoon by a person with moderate technical and computer skills. Onset's weather station runs for up to one year on 4 AA batteries and will hold 500,000 measurements in memory. Onset uses "smart sensor" technology in which the datalogger detects the type of sensor that is connected and then automatically calculates the proper output units from the sensor data. MED used an Onset weather station on an ecological preserve in North Carolina for 2.5 years with only minor problems in its operation (Fig. 1).

Dataloggers should be placed in some type of enclosed structure to protect them from the weather and vandals. Most manufacturers offer such containers, although small plastic toolboxes or waterproof storage boxes used on boats provide less expensive alternatives. In areas exposed to direct sunlight, it may be necessary to shade the enclosure or paint it white to prevent overheating. In humid environments a desiccant (e.g., silica gel) can be placed within the enclosure to maintain operating conditions of the datalogger. Burial also reduces the range of temperatures to which the datalogger is exposed. In areas prone to flooding dataloggers can be suspended from trees with ropes. To prevent vandalism and theft, we have sometimes buried

enclosures to hide them.

Another frequent problem is animal-damage to sensors or sensor wires. Because thermocouples or thermistors often must be placed at considerable distances from the datalogger, they are particularly vulnerable. Moose (*Alces alces*) and other large mammals have damaged thermocouples or pulled them loose from our dataloggers, and rodents have chewed through the insulation on connecting wires. Burying or covering the exposed parts of the wires with moderate sized rocks or logs may help to prevent such damage as does enclosing thermistor wires in small diameter PVC pipe.

SINGLE-CHANNEL DATALOGGERS

Single-channel dataloggers have several advantages relative to multi-channel systems. They are much simpler and less expensive alternatives when only one or a few environmental variables need to be measured. Additionally, single-channel dataloggers are ideal if environmental variables must be measured at locations some distance apart. Also, because of their small size, single-channel loggers are often much easier to deploy, protect from environmental conditions, and hide from potential vandals. Specially designed, single-channel dataloggers that measure temperature, solar and lunar radiation, barometric pressure, relative humidity, precipitation, soil moisture, or wind speed are available.

We have had experience using two types of single-channel dataloggers. For most of our applications requiring monitoring of a single or few variables, we have used dataloggers from Onset Computer Corporation (U. S. \$60-\$400). These single-channel dataloggers are easily programmed and their stored data easily downloaded through a serial or USB interface using the BoxCar software available from Onset. The software runs on Windows or Macintosh operating

systems, is easy to use, automatically recognizes the type of datalogger attached, and allows downloaded data to be easily exported in text or Microsoft Excel formats for analysis.

We have also used the iButton Thermochron datalogger, developed by Dallas Semiconductor, which provides a considerably smaller alternative to many of the single-channel dataloggers when temperature measurements are required. Thermochrons are 5.9 mm high by 17.4 mm in diameter (approximately the size of four stacked dimes), and weigh 3.12 g. In addition, Thermochrons are relatively inexpensive (approximately U.S. \$15-\$29 each). Thermochrons are reliable and accurate in laboratory calibrations (Angilletta and Krochmal 2003) and are programmed through a serial or USB computer interface. Thermochrons have a somewhat limited capacity, however, recording 2048 – 8192 or time and date-stamped temperature readings with 0.125-0.5°C resolution (depending on model), at sampling intervals selected by the user (Angilletta and Krochmal 2003; Roberts and Thompson 2003; Grayson and Dorcas 2004; Harden et al. in press; Harden and Dorcas in press).

Both Onset Computer and Dallas Semiconductor provide software and interface cables that allow downloading and limited programming of their dataloggers using personal digital assistants (PDA's) running the Palm operating system. We have used PDA's to download data from Onset dataloggers in the field and found them to be very reliable. After downloading, the PDA is connected to a computer, and the downloaded data are transferred to it. We have also used tablet PC's to interface with our dataloggers in the field. Although a field computer (i.e., laptop) is larger than a PDA, we find the flexibility provided by the standard Microsoft Windows operating system makes transfer of data less complicated and reduces time spent learning or teaching someone how to use PDA-based software. It should be possible to connect and use PDA's running the MS Pocket PC operating system to program and download data from most

dataloggers that require connection to a MS Windows environment, although we have no experience with this procedure.

Environmental Sensors

In the following sections we describe the sensors that are most often used with dataloggers to measure important environmental variables. For weather stations, sensors are usually mounted on an instrument tripod which an investigator can purchase from a supplier or constructed him- or herself. Figure 1 shows examples of measurements of air and soil temperatures, radiation, relative humidity, and wind speed measurements plotted versus hour of day. We do not have extensive experience with measuring all of these variables and thus have had to rely on the literature or advice from engineers or other scientists to prepare some of the following material. See Fritschen and Gay (1979), WMO (1983), Marshall and Woodward (1985), Finklestein et al. (1986), Percy et al. (1989), Skaar et al. (1989), Campbell (1990), and Tanner (1990) for more information on sensor instrumentation.

TEMPERATURE

For a variety of reasons, thermocouples are often the preferred sensors to use in field studies requiring automated temperature measurements. They are relatively accurate, inexpensive, come in a wide range of sizes, and respond quickly, and their signal does not diminish over long distance, which may be especially important when using multi-channel dataloggers (Percy et al. 1989). For temperature measurements in the range of biological interest (-70 to 100°C), Type T (copper-constantan) thermocouples are most appropriate because this combination of metals produces a relatively large voltage that changes linearly with temperature (ca. 40 $\mu\text{V}/^\circ\text{C}$) within

the range of interest. Thermocouples come in a wide range of sizes; 24-gauge (0.5 mm diameter) wire is commonly used for measuring water, soil, and air temperatures. Thermocouple wire is relatively cheap (about U.S. \$1.75/meter) depending on the type, size, and quality of the wire. Thermocouples can be purchased or easily made by stripping the ends of the wire, twisting the exposed ends together, and then soldering them (Pearcy et al. 1989). The actual site of the temperature measured lies at the first junction of the twisted wires (i.e., the thermocouple). Thermocouples usually do not have to be individually calibrated. Potential problems with thermocouples include heat conduction via the thermocouple wire and inaccurate measurements of the reference temperature (usually taken where the thermocouple wire attaches to the datalogger).

Thermistors (temperature sensitive resistors) are another device commonly used to measure temperature. They are highly sensitive and accurate, and respond rapidly. However, thermistors are more expensive and more delicate than thermocouples, cannot easily be used over long distances, and sometimes require individual calibration. Some dataloggers can read both thermocouples and thermistors easily, whereas other dataloggers read only one type, or read a second type only with difficulty.

Most single-channel, temperature dataloggers use thermistors as the temperature sensor. However, some single-channel dataloggers are able to read thermocouples. Some single-channel dataloggers come with the sensor built into the logger, and thus temperature fluctuation of the entire datalogger (or a portion of it) is actually measured. Others provide the option of plugging in a thermistor or thermocouple for measurement some distance away from the datalogger. Many single-channel dataloggers designed to measure temperature do not require any special housing and can simply be mounted or positioned where desired. Specially designed,

waterproof, single-channel dataloggers for measuring water temperature (e.g., Stowaway-Tidbits, Onset Computer) are available and can be tethered and tossed into the water. Other dataloggers may be used to monitor water temperature, but may require waterproof housing with the temperature sensor (e.g., thermistor) exiting the housing through a sealed port. We have successfully used wide-mouthed plastic bottles (i.e., Nalgene) for this purpose.

We usually measure air temperatures at animal height (e.g., 1 cm) and/or at 2 m (a standard reference height for meteorological stations), water temperatures on the bottom and 1 cm from the upper surface, and soil temperatures from at least two depths (e.g., 1 and 20 cm) as surrogates for burrow temperatures. Thermocouples used to measure air temperatures should be shaded unless they are small and highly reflective (e.g., painted white). Some manufacturers provide radiation shields for temperature dataloggers and sensors at a moderate cost. To measure shallow water temperature in aquatic environments where the water depth may fluctuate greatly over short periods (hours or days), we attach the end of the thermistor or thermocouple to a float (e.g., a bobber used for fishing) which is attached loosely to a metal rod anchored in the bottom so that the sensor can rise and fall with fluctuating water levels.

PHYSICAL MODELS AND OPERATIVE TEMPERATURES

Temperature is one of the most important factors influencing the activity of reptiles (especially in the temperate zone) and, thus, our ability to determine their presence and abundance (Peterson et al. 1993). For this reason, it is important to describe the thermal environments of reptiles accurately. The thermal environment of submerged, aquatic reptiles (e.g., some turtles) can be characterized relatively easily by measuring the temperature of the surrounding water.

Describing the thermal environments of terrestrial reptiles is more complex because a variety of

factors interact to determine their body temperatures. These factors include air temperature, substrate temperature, radiation, humidity, soil moisture, wind speed, and animal properties such as size, shape, and reflectivity (Bakken 1992). A single-number representation of the thermal environment that incorporates these factors is the **operative temperature** (Bakken and Gates 1975; Bakken 1992). Operative temperatures can be calculated using computer models of heat transfer, but this approach may be difficult to apply at small spatial scales and requires considerable instrumentation and expertise.

A simpler and less expensive approach for measuring operative temperatures involves the use of physical models which incorporate animal properties such as size, shape, and reflectivity (Bakken and Gates 1975). This approach has been applied with considerable success to dry-skinned ectothermic vertebrates (i.e., reptiles; see Crawford et al. 1983, Peterson 1987, and Grant and Dunham 1988). Many investigators use hollow casts of actual reptiles as models. A convenient alternative is a section of hollow copper tubing. We found that a model made of copper tubing of approximately the same length and diameter as a real snake and painted to match the reflectance of the dorsal surface of the species generally matches the temperature of the real snake closely (Peterson et al. 1993). Temperatures of models of small reptiles tend to match those of the animal closely. In contrast, the thermal inertia of large reptiles usually results in substantial lag before the actual body temperatures of these animals reach those of hollow models. Vitt and Sartorius (1999) found that self-contained dataloggers such as Tidbits (Onset) may serve as good estimators of body temperature for some small reptiles (e.g., many lizard species). Shine and Kerney (2001) provided a detailed analysis of various physical parameters that may affect physical models.

HUMIDITY

Electrical resistance sensors and capacitance sensors provide convenient ways to measure atmospheric water vapor automatically (Tanner 1990). Costs range from U.S. \$85 to U.S. \$400.

Some of these sensors require that the datalogger provide an AC excitation voltage. Sensor elements need to be individually calibrated at least annually and may need to be replaced periodically. Some electrical humidity sensors may be damaged by condensation or air contaminants (Campbell 1990). Skaar et al. (1989) Among commercial hygrometers, ventilated wet-bulb, dry-bulb psychrometers are the most accurate but also more expensive, require power to run the fan, require attention to keep the water reservoir filled, and do not read accurately below freezing.

Onset Computer Corporation provides a dual-channel datalogger (HOBO Pro RH/Temp) that measures atmospheric water vapor and air temperature. The Boxcar software can calculate and output temperature, relative humidity, and dew point. Cost is approximately U.S. \$200 with the recommended rain shield.

PRECIPITATION

Precipitation can be measured automatically with a tipping bucket rain-gauge connected to a pulse counting channel on a datalogger (Tanner 1990). When a specified depth of water has collected, the bucket tips and empties. The datalogger records the number of tips. . Resolution in the range of 0.1 to 0.2 mm is possible (WMO 1983). Onset single-channel event recorders can be used to log data from a single tipping bucket rain gauge (cost is about U.S. \$400).

Tipping buckets can be heated so that winter precipitation (snow, ice) will melt and the water will drain from the bucket. Weighing bucket rain gauges provide a more accurate but more

expensive way to measure precipitation (Tanner 1990).

RADIATION

Two types of solar radiation sensors (pyranometers) that are commonly used with dataloggers are silicon photocells (e.g., Li-Cor LI2000SB) and thermopile devices (e.g., Eppley Model PSP, Kipp and Zonen Model CM11). Silicon cells are considerably less expensive than the thermopile devices (approximately U.S. \$200 vs. \$1300-\$3000). However, because the spectral response of silicon cells is limited (400-1100 nm), they should not be used under vegetation canopies or to measure reflected radiation (Tanner 1990).

Lunar radiation can also affect the levels of activity of some reptiles (Clarke et al. 1996).

Single-channel radiometers that measure solar and lunar radiation are available from Onset Computer. We successfully used one of these (Stowaway LI) to measure solar and lunar radiation as part of a study examining factors affecting snake activity in South Carolina (J. Willson unpub. data). Light intensity is recorded on a logarithmic scale (\log Lumens/m²) allowing easy visualization of lunar and solar radiation (Fig. 2).

WIND SPEED

Wind speed can be measured automatically with a cup anemometer and the pulse counting channel of a datalogger. Cup anemometers are omnidirectional, have linear responses, and are reasonably precise (Campbell 1990). Factors to consider when selecting an anemometer include size, the range of wind speeds over which the sensor operates (especially the starting and stopping thresholds), cost, and durability. Propeller anemometers have lower thresholds and can measure wind direction, but they are more expensive (Campbell 1990). We usually mount

anemometers at a height of 2 m. If more than one anemometer is available, wind profiles can be determined so that the 2 m wind speed can be used to calculate wind speeds at other heights.

Automated Monitoring of Animals

Monitoring animal activity and correlating that activity with variation in environmental variables allows an investigator to predict when animals are likely to be most active and thus, most easily encountered for inventory or monitoring purposes (Peterson and Dorcas 1992). Additionally, some automated systems can provide information on animal locations, so habitats most often used by animals can be identified and sampling efforts further refined. types of reptiles are more easily monitored with automated devices than other types. For example, satellite GPS may be useful for monitoring large chelonians such as sea turtles, but it is inappropriate work for smaller species because of the size of the equipment. Below, we review a variety of automated methods that have been used to monitor reptile populations or that have been used to monitor other animal groups but can be adapted for some species of reptiles.

AUTOMATED RADIOTELEMETRY

Radiotelemetry has been used extensively to monitor the movements and habitat use of many animals, including many species of reptiles (Millsbaugh and Marzluff 2001). Automated systems used in conjunction with radiotelemetric techniques can also be used to monitor body temperature automatically and continuously in many species of reptiles. Body temperature variation, especially when combined with environmental temperatures, can then be used to make accurate inferences about activity patterns and microhabitat use (Fig. 3).

Generally, the factor determining whether reptilian species are suitable for

radiotelemetric projects is size; larger animals are more easily outfitted with radiotransmitters. However, the continued development and refinement of telemetry equipment is making it possible to use automated telemetry techniques to monitor smaller and smaller species. For example, we used an automated system with a small, surgically-implanted transmitter (ca. 2 g; BD-2, Holohil Ltd.) to monitor the body temperatures of a 35-g, male rubber boa for 3 months. . The snake fared well, gaining 15 g during the study period.

For snakes, most transmitters must be surgically implanted, and thus, temperature-sensitive transmitters monitor body temperatures accurately and automatically (Peterson et al. 1993). These transmitters use a temperature-sensitive resistor (thermistor), which causes the pulse rate of the transmitter to vary positively with temperature. Addition of a temperature sensitive option to a typical transmitter generally adds about U.S. \$50 to \$75 to the cost, but does not substantially increase the size or mass of the transmitter. Temperature-sensitive transmitters should be calibrated in a waterbath before surgical implantation, and equations that describe the relationship between temperature and interpulse interval should be developed (we typically use a second or third order polynomial). Some manufacturers calibrate temperature-sensitive transmitters for the researcher, but we recommend that s/he verify those calibrations. Also, due to unfortunate experiences of some of our colleagues, we highly recommend that transmitters be calibrated after removal to check for a shift in the temperature sensitivity.

A variety of automated systems have been developed to monitor animals outfitted with radiotransmitters. Automated systems that can monitor temperature-sensitive radiotransmitters usually are designed to record the rate of the interpulse interval. The simplest of these systems monitors only one animal (i.e., one frequency) and has a recycling timer that automatically turns a radio receiver that is tuned to the transmitter frequency and a cassette tape recorder that records

the pulse rate as an audible signal on and off at regular intervals (Beaupre and Beaupre 1994; Cobb 1994; Lutterschmidt et al. 1996). The tape must then be manually decoded (i.e., the pulse intervals timed) using a stop watch or other timer.

More advanced systems can systematically scan over many frequencies (i.e., monitor multiple animals), time the interpulse intervals, and then store the data, which can later be downloaded into a computer. We have used a Fast Data System (Telonics) for this purpose to study body temperature variation in free-ranging garter snakes (*Thamnophis elegans*; Peterson 1987) and rubber boas (*Charina bottae*; Dorcas and Peterson 1998). More advanced systems have been developed that use dataloggers to turn the receivers on and off, change receiver frequencies, and time interpulse intervals (Grothe 1992; Cobb 1994). LoTek has developed an elaborate, but expensive (ca. U.S. \$14,000) system that allows the user to enter calibration values so that interpulse intervals are automatically converted into body temperatures (S. J. Beaupre pers. comm.).

Some manufacturers can outfit their transmitters with activity switches (usually mercury switches) that allow detection of animal movements (Grothe 1992; Cobb 1994). When combined with temperature-sensitive capabilities and automatically monitored, these units allow for strong inferences regarding activity patterns and microhabitat use (Fig. 3). Because the amount of movement necessary to trigger the switch depends on the position of the sensor in the animal, we recommend only intra-individual comparisons. Additionally, these activity transmitters should be calibrated to determine how much movement is required to trigger the sensor.

ANIMAL TEMPERATURE MONITORING USING DATALOGGERS

Automated monitoring of body temperature is possible with temperature dataloggers attached to (or implanted in) to reptiles. One of us (MED) used Onset Tidbit dataloggers to monitor the body temperatures of eastern diamondback rattlesnakes (*Crotalus adamanteus*) automatically, while tracking their movements using radiotelemetry. Tidbits were programmed and coated in a polymer (Elvax by Minimitter) before implantation into the body cavity. By examining body temperature plots combined with environmental data, activity patterns and microhabitat use were able to be inferred (Fig. 4)

We have successfully used Thermochron iButtons) to measure seasonal variation in body temperature and infer activity patterns (e.g., basking) in painted turtles (*Chrysemys picta*) inhabiting a farm pond (Fig. 5; Grayson and Dorcas 2004). We glued the Thermochrons to plastic cable ties and attached them through holes drilled in the marginal scutes of the carapace. After programming, Thermochrons were sealed using plastic tool dip (Plasti Dip International); a fast drying liquid plastic traditionally used to coat the grips of hand tools). We recovered 41 Thermochrons from the turtles, and data from all of them were successfully downloaded upon recovery. We conducted similar studies with diamondback terrapins (*Malaclemys terrapin*) mud turtles (*Kinonsternon subrubrum*) and were able to easily distinguish periods of basking, microhabitat use, and aquatic and terrestrial activity (Harden et al. in press; Harden and Dorcas in press).

AUTOMATED MONITORING OF PIT TAGS

Passive integrated transponders (or PIT tags) have become a widely used method of individually marking a variety of animals (Gibbons and Andrews 2004). Various automated systems for monitoring animals implanted with PIT tags have been developed (e.g., for fish, Prentice et al.

1990; voles, Harper and Batzli 1996; and bats Kunz 2001). Generally, animals implanted with PIT tags or with PIT tags attached to them are monitored as they pass through an opening or over a specific area where a PIT tag reader is placed. Boarman et al. (1998) used Psion dataloggers to develop an automated system to read PIT tags to monitor the movements of desert tortoises (*Gopherus agassizii*) when diverted under highways through culverts. Each time a tortoise passed over the reader's detecting coil, the system recorded its PIT tag identification number, time of day, date, and period during which the tag was within reading distance of the coil. Gruber (2004) used an automated PIT tag reading system to monitor the activity of geckos (*Gehyra variegata*). He used a datalogger connected to a PIT tag reading coil that encircled the base of a tree to detect the passage of geckos to which PIT tags had been glued.

Pit tags may prove ideal monitoring the activities of reptiles in certain other situations. The hibernacula of some snakes, especially in northern latitudes, may have discrete openings through which the movements of snakes implanted with PIT tags could be automatically monitored relatively easily. PIT-tagged reptiles passing through openings in drift fences could also be monitored using automated PIT tag readers (Gibbons and Semlitsch 1982).

Temperature-sensitive PIT tags have been used to manually monitor thermoregulation in corn snakes (*Elaphe guttata*; Roark and Dorcas 2000) and rubber boas (*Charina bottae*; Zhange et al. 2007). PIT tag readers that can monitor temperatures and read such PIT tags (BioThermal TX1440BBT) from a short distance away (e.g., 25 cm; BioMark; Boise ID) may allow automated monitoring of reptiles implanted with temperature-sensitive PIT tags.

AUTOMATED GLOBAL POSITIONING SYSTEMS

Elaborate automated systems for tracking animals with attached global positioning systems

(GPS) have been developed for many species of large mammals and some birds (Rogers 2001). Several types of systems can be used to transmit location data from the GPS to the investigator. Some systems use radio signals, more sophisticated systems use satellite links (Argos satellite system), and others store data on board the GPS unit until it is retrieved. For many investigators, however, costs of such systems are prohibitive. Units that transmit data via radio signals or satellite links range from approximately U.S. \$3500 to \$5000 each. Systems that store data on board are considerably cheaper (ca. U.S. \$2000-2500).

Historically, only large reptiles have been suitable for GPS monitoring because of the cost and weight of the system. Consequently, use of automated GPS in reptiles has been limited primarily to studies of sea turtles and the very largest freshwater turtles. However, smaller systems, designed for birds, that weigh less than 20 grams (TAV-2417 Argos, Telonics), are now available and could be used on (or implanted into) some reptile species. Satellite GPS systems have been successfully used to monitor movements of immature loggerhead sea turtles (*Caretta caretta*; Cardona et al. 2005). Even fine-scale movements can be monitored allowing precise data on location and depth to be collected (Yasuda and Arai 2005). Satellite transmitters have also been successfully used to monitor the movements of South American river turtles (*Podocnemis expansa*) in Brazil (R. Vogt pers. comm.). Balazs et al. (1996) has provided details of how to attach satellite GPS transmitters to the carapace of turtles and similar techniques could be applied to other reptilian taxa. If funding were sufficient, automated GPS techniques could likely be applied to medium to large reptiles and possibly even to some crocodylians.

ANIMAL MONITORING WITH PHOTOGRAPHY

The use of automatically controlled cameras provides a unique opportunity to observe the

activities of animals remotely, providing information on animal activity useful for optimizing inventory and monitoring programs. Such systems may also be used to document the occurrence of rare species unlikely to be detected by sampling using manual techniques (i.e., direct observation). Several investigators have used cameras that take a still image when a light beam is broken or when a switch is mechanically triggered. For example, Tuberville and Burke (1994) used 35-mm-film cameras that were activated by the interruption of a light beam to detect potential predators of freshwater-turtle nests. DeVault and Rhodes (2002) used 35-mm-film cameras triggered by a mechanical switch to investigate scavengers. Their camera, in a weather-resistant case attached to a tree, was triggered when a dead rat, which was holding down the switch, was moved. It took an image of the area surrounding the dead rat. Although not included in their published paper on mammal scavengers, several snakes were discovered scavenging the dead rats used as bait in the study (T. L. DeVault, pers. comm.). Guyer et al. (1997) described in detail the construction of a system that uses a modified digital camera (Canon SureShot Max/Date) in conjunction with a pressure switch plate to monitor vertebrate activity. The use of a digital camera for applications such as this greatly increases the image capacity of the system and because film developing is not required, greatly reduces costs. Campbell Scientific produces a digital camera (model CC640) for use in harsh environments that can easily be triggered by timing devices or by dataloggers.

Numerous investigators have used automatically controlled still and video cameras to record predation (including by snakes) at bird nests (e.g., Renfrew and Ribic 2003; Peterson et al. 2004). Most researchers use time-lapse video (2-5 frames/sec) with which tapes last a relatively long time (up to 24 h). However, triggering a video camera to record based on stimuli such as a switch or breaking of a light beam should be possible and may allow the investigator to

deploy the system without maintenance for longer periods because tape is not used when the switch is not triggered. Furman Diversified produces a wide range of video camera systems specifically designed for use in the field.

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LITERATURE CITED

- Angilletta, M. J., and A. R. Krochmal. 2003. The thermochron: a truly miniature and inexpensive temperature-logger. *Herpetological Review* 34:31-32.
- Bakken, G. S. 1992. Measurement and application of operative and standard operative

- temperatures in ecology. *American Zoologist* 32:194-216.
- Bakken, G. S., and D. M. Gates. 1975. Heat-transfer analysis of animals: Some implications for field ecology, physiology, and evolution. Pp. 255-290. In D. M. Gates and R. B. Schmerl (eds.), *Perspectives of Biophysical Ecology*. Springer-Verlag, New York.
- Balazs, G. H., R. K. Miya, and S. C. Beavers. 1996. Procedures to attach a satellite transmitter to the carapace of an adult green sea turtle, *Chelonia mydas*. Proceedings of the 15th Annual Symposium on Sea Turtle Biology and Conservation. NOAA Technical Memorandum NMFS-SEFSC-37:21-26.
- Beaupre, S. J., and R. W. Beaupre. 1994. An inexpensive data collection method for temperature telemetry. *Herpetologica* 50:509-516.
- Boarman, W. I., M. L. Beigel, G. C. Goodlett, and M. Sazaki. 1998. A passive integrated transponder system for tracking animal movements. *Wildlife Society Bulletin* 26:886-891.
- Campbell, G. S. 1990. *Biophysical Measurements and Instrumentation: A Laboratory Manual for Environmental Physics*. Department of Agronomy and Soils, Washington State University, Pullman, Washington.
- Cardona L., M. Revelles, C. Carreras, M. San Felix, M. Gazo, and A. Aguilar. 2005. Western Mediterranean immature loggerhead turtles: Habitat use in spring and summer assessed through satellite tracking and aerial surveys. *Marine Biology* 147:583-591.
- Clarke, J. A., J. T. Chopko, and S. P. Mackessy. 1996. The effect of moonlight on activity patterns of adult and juvenile prairie rattlesnakes (*Crotalus viridis viridis*). *Journal of Herpetology* 20:192-197.
- Cobb, V. A. 1994. The ecology of pregnancy in free-ranging great basin rattlesnakes (*Crotalus viridis lutosus*). Unpubl. Ph.D. dissert., Idaho State University, Pocatello, Idaho.

- Crawford, K. M., J. R. Spotila, and E. A. Standora. 1983. Operative environmental temperature and basking behavior of the turtle *Pseudemys scripta*. *Ecology* 64:989-999.
- DeVault, T. L., and O. E. Rhodes, Jr. 2002. Identification of vertebrate scavengers of small mammal carcasses in a forested landscape. *Acta Theriologica* 47:185–192.
- Dorcas, M. E., and C. R. Peterson. 1998. Daily body temperature variation in free-ranging rubber boas. *Herpetologica* 54:88-103.
- Finklestein, P. L., J. C. Kaimal, J. E. Gaynor, M. E. Graves, and T. J. Lockhart. 1986. Comparison of wind monitoring systems. Pt. I. In situ sensors. *Journal of Atmospheric and Oceanic Technology* 3:583-593.
- Fritschen, L. J., and L. W. Gay. 1979. *Environmental Instrumentation*. Springer-Verlag, New York.
- Gibbons, J. W., and K. M. Andrews. 2004. PIT tagging: Simple technology at its best. *BioScience* 54:447-454.
- Gibbons, J. W., and R. D. Semlitsch. 1982. Terrestrial drift fences with pitfall traps: An effective technique for quantitative sampling of animal populations. *Brimleyana* 1982:1-16.
- Grant, B. W., and A. E. Dunham. 1988. Thermally imposed time constraints on the activity of the desert lizard *Sceloporus merriami*. *Ecology* 69:167-176.
- Grayson, K. L., and M. E. Dorcas. 2004. Seasonal temperature variation in the painted turtle (*Chrysemys picta*). *Herpetologica* 60:325-336.
- Grothe, S. 1992. Red-tailed hawk predation on snakes: The effects of weather and snake activity. Unpubl. M.S. thesis. Idaho State University, Pocatello, Idaho.
- Gruber, B. 2004. Measuring activity of geckos with an automatic movement monitoring system. *Herpetological Review* 35:245-247.

- Guyer, C., C. T. Meadows, S. C. Townsend, and L. G. Wilson. 1997. A camera device for recording vertebrate activity. *Herpetological Review* 28:135-140.
- Harden, L. A., N. A. DiLuzio, J. W. Gibbons, and M. E. Dorcas. 2007. Spatial and thermal ecology of diamondback terrapins (*Malaclemys terrapin*) in a South Carolina salt marsh. *Journal of the North Carolina Academy of Science* 123:154-162.
- Harden, L. A. and M. E. Dorcas. *In press*. Using thermal biology to investigate habitat use and activity of eastern mud turtles (*Kinosternon subrubrum subrubrum*) on a golf course. *In* R. E. Jung and J. C. Mitchell (eds.), *Urban Herpetology*. *Herpetological Conservation* Vol. 3, Society for the Study of Amphibians and Reptiles. Salt Lake City, UT.
- Harper, S. J., and G. O. Batzli. 1996. Monitoring use of runways by voles with passive integrated transponders. *Journal of Mammalogy* 77:364-369.
- Kunz, T. H. 2001. Seeing in the dark: Recent technological advances for the study of free-ranging bats. *Bat Research News* 42:91.
- Lutterschmidt, W. I., J. J. Lutterschmidt, and H. K. Reinert. 1996. An improved timing device for monitoring pulse frequency of temperature-sensing transmitters in free-ranging animals. *American Midland Naturalist* 136:172-180.
- Marshall, B., and F. I. Woodward (eds.). 1985. *Instrumentation for Environmental Physiology*. Cambridge University Press, Cambridge, England.
- Millspaugh, J. J., and J. M. Marzluff. 2001. *Radio tracking and animal populations*. Academic Press, San Diego, California..
- Pearcy, R.W., J. Ehleringer, H. A. Mooney, and P. W. Rundel. 1989. *Plant Physiological Ecology: Field Methods and Instrumentation*. Chapman Hall, New York.
- Peterson, C. R. 1987. Daily variation in the body temperatures of free-ranging garter snakes.

Ecology 68:160-69.

- Peterson, C. R., and M. E. Dorcas. 1992. The use of automated data acquisition techniques in monitoring amphibian and reptile populations. Pp. 369-378 *In* D R. McCullough and R. H. Barrett (eds.), *Wildlife 2001: Populations*. Elsevier Scientific, Barking, Essex, England.
- Peterson, C. R., and M. E. Dorcas. 1994. Automated data acquisition. Pp. 47-57. *In* W. R. Heyer, M. A. Donnelly, R. W. McDiarmid, L-A. C. Hayek, and M. S. Foster (eds.), *Measuring and Monitoring Biological Diversity, Standard Methods for Amphibians*. Smithsonian Institution Press, Washington, D. C.
- Peterson, C. R., A. R. Gibson, and M. E. Dorcas. 1993. Snake thermal ecology: The causes and consequences of body temperature variation. Pp. 241-314 *In* R. A. Seigel and J. T. Collins (eds.), *Snakes: Ecology and Behavior*. McGraw-Hill , New York.
- Peterson, B.L. B. E. Kus, and D. H. Deutschman. 2004. Determining nest predators of the Least Bell's Vireo through point counts, tracking stations, and video photography. *Journal of Field Ornithology* 75:89-95.
- Prentice, E. F., T. A. Flagg, C. S. McCutcheon, and D. F. Brastow. 1990. PIT-tag monitoring systems for hydroelectric dams and fish hatcheries. *American Fisheries Society Symposium* 7:317-322.
- Renfrew, R. B., and C. A. Ribic. 2003. Grassland passerine nest predators near pasture edges identified on videotape. *Auk* 120:371-383.
- Roark, A. W., and M. E. Dorcas. 2000. Regional body temperature variation in corn snakes measured using temperature-sensitive passive integrated transponders. *J. Herpetol.*

34:481-485.

- Roberts, K. A., and M. B. Thompson. 2003. Reconstructing thermochron buttons to reduce size and weight as a new technique in the study of small animal thermal biology. *Herpetological Review* 34:130-132.
- Rogers, A. R. 2001. Recent telemetry technology. Pp. 79-123 *In* J. J. Millspaugh and J. M. Marzluff (eds.), *Radio Tracking and Animal Populations*. Academic Press, San Diego, California.
- Shine, R., and M. Kearney. 2001. Field studies of reptile thermoregulation: How well do physical models predict operative temperatures? *Functional Ecology* 15:282-288.
- Skaar, J., K. Hegg, T. Moe, and K. Smedsurd. 1989. *WMO international hygrometer intercomparison (Norway, 1987-1989)*. World Meteorological Organization, Geneva, Switzerland.
- Tanner, B. D. 1990. Automated weather stations. *Remote Sensing Reviews* 5:73-98.
- Tuberville, T. D., and V. J. Burke. 1994. Do flag markers attract turtle nest predators? *Journal of Herpetology* 28:514-516.
- Vitt, L. J., and S. S. Sartorius. 1999. HOBOS, Tidbits, and lizard models: The utility of electronic devices in field studies of ectotherm thermoregulation. *Functional Ecology* 13:670-674.
- WMO. 1983. *Guide to Meteorological Instruments and Methods of Observation*. World Meteorological Organization No. 8, 5th ed., Geneva, Switzerland.
- Yasuda, T., and N. Arai. 2005. Fine-scale tracking of marine turtles using GPS-Argos PTTs. *Zoological Science* 22:547-553.
- Zhang, Y., M. C. Westfall, K. C. Hermes, and M. E. Dorcas. 2007. Physiological and behavioral control of heating and cooling rates in rubber boats, *Charina bottae*. *J. Thermal Biol.* 33:7-11.

Figure Captions

Figure 1. Variation in wind, precipitation, relative humidity, solar radiation, air and 20 cm soil temperatures sampled using a weather station (Onset Computer Corp.) every 30 minutes for an entire day 4 December 2005 on the Davidson College Ecological Preserve.

Figure 2. Variation in light intensity (solar and lunar radiation) over a 20-day period in November 1994 at Ellenton Bay on the Savannah River Site, SC. Note the progressive delay in moon rise from days 316 until 327 and the absence of measurable lunar radiation after day 328.

Figure 3. Variation in the body temperature and activity of a great basin rattlesnake (*Crotalus lutosus*) in southeastern Idaho over an entire day in the summer of 1991. Temperature was monitored using a thermistor within a surgically implanted radiotransmitter which varied the transmitter pulse rate. Activity was determined by toggles of a mercury switch within the transmitter. Transmitter pulse rate was monitored with an automated system described in the text. Environmental temperatures (T_e) were determined physical snake models and a Campbell datalogger (Cobb, 1994).

Figure 4. Variation in body temperature of an eastern diamondback rattlesnake (*Crotalus adamanteus*) over a one-week period in August 1999 in southeast South Carolina. Body temperature was measured using a surgically-implanted dataloggers (see text). Environmental temperatures were measured using thermocouples and a multi-channel datalogger (CR-10, Campbell Scientific, Logan UT). Note that the snake apparently was in a shallow burrow the first 3 days and then remained on the surface, but in the shade for the rest of the week.

Figure 5. Seasonal temperature variation of one male *Chrysemys picta* over 1 yr monitored using a Thermochron iButton (Grayson and Dorcas 2004). Water temperatures were measured using Onset Tidbit dataloggers. Basking temperatures were designated as those 6 C greater than water temperature.

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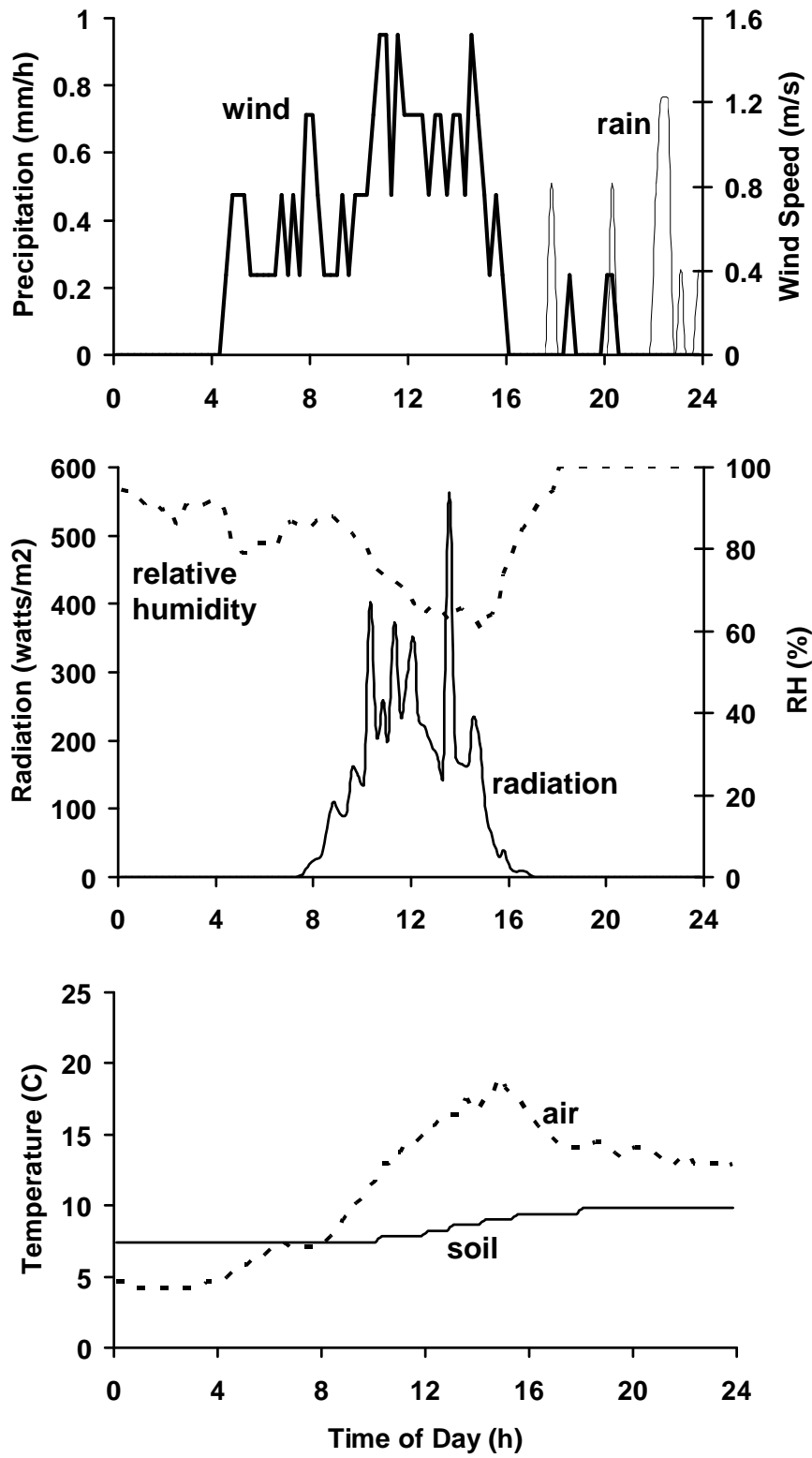
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Dorcas and Peterson – Figure 1

