Research on North American Tortoises: A Critique With Suggestions for the Future

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Abstract. Research and conservation of North American tortoises (genus *Gopherus*) increased greatly in the past 20 years, but the quantity and quality of the studies of each of the four species vary widely. Only work on the gopher tortoise (*G. polyphemus*) was sufficiently broad in geographic scope and in coverage of topics to begin answering basic biological questions. More rigorous studies of the biology of all four species are needed for comprehensive information, including better definitions or evaluations of distribution, range limits, use of habitats, life histories, juvenile ecology, and physiology. An obstacle to past and current research is the preponderance of unpublished literature and lack of scientific hypotheses, especially of studies on desert tortoises (*G. agassizii*). Important management decisions have been made without adequate knowledge about the biology of the affected species. We suggest that future studies of all four species should be comparable (e.g., analyze growth rates between species), test hypotheses, and be designed for publication in peer-reviewed outlets. These efforts will improve the research and conservation of North American tortoises.

Key words: Bibliography, *Gopherus*, gray literature, habitat evaluations, methodology, reproduction studies.

Surveys and studies of tortoises, particularly of the desert tortoise (*Gopherus agassizii*) and the gopher tortoise (*G. polyphemus*), increased profoundly in the 1970's and 1980's. However, the work did not lead to an equal increment in the understanding of the biology of North American tortoises for reasons we address here. Specifically, this paper provides a review of published literature on North American tortoises, a critique of current studies and research on tortoises, and suggestions to

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improve the study and conservation of North American tortoises.

Adequacy of the Research

Summaries of Publications

Bibliographies on North American tortoises (Douglass 1975, 1977; Hohman et al. 1980; Diemer 1981; Beaman et al. 1989) list hundreds of papers, most of which were not reviewed by peers or are difficult to obtain. This paper partially fills the need for tabulated recent literature (Tables 1–4), but we selected only major publications (judged as seminal works), key historic references, and advancements in the study of each species.

Published Literature

The quantity and quality of research on each species of the North American tortoises differ markedly. Although the geographic scope of work on the Berlandier's tortoise (*G. berlandieri*) is limited, studies of this species have been exceptional because of the diversity of topics and intensive methodology (Table 1) and because almost all studies were published in journals or books. The findings on the Bolson tortoise (*G. flavomarginatus*) are remarkable because the animal was only recently discovered (Legler 1959) and ecological studies of the species have been under way for only about 10 years. To the credit of the investigators, most papers on the Bolson tortoise are available in outlets for peer-reviewed publications (Table 2).

Numerous studies of the gopher tortoise (Table 3) and desert tortoise have been conducted (Table 4). Based on the number of the studies, expanse of the studies over the species' range, diversity of the topics, and publication of results in journals, the best-studied North American tortoise is the gopher tortoise. Many graduate students selected this species as the topic of their theses—for example, parts of two theses are in this volume (Linley and Mushinsky 1994; Wilson et al. 1994). Many topics have been studied in detail (Table 3). Several comprehensive studies of the ecology and other topics on the desert tortoise have been completed (Table 4). The extent of past research does not preclude more work but points out existing information.

Unpublished Literature

Unlike information on the other species of North American tortoises, much information

Table 1. Selected publications on the biology of *Gopherus berlandieri.*

Ecology	Strecker (1927); Hamilton (1944); Mittleman (1947); Auffenberg (1969); Auffenberg and Weaver (1969); Rose and Judd (1982); Bury and Smith (1986)
Growth	Judd and McQueen (1980); Germano (1994b)
Morphology	True (1882); Smith and Brown (1946); Paxson (1961);Auffenberg (1976); Auffenberg and Franz (1978a); Bramble (1982); Rose and Judd (1991); Crumly (1994); Germano (1993)
Reproduction	Brown (1964); Auffenberg and Weaver (1969); Rose and Judd (1982); Judd and Rose (1989)
Longevity	Judd and McQueen (1982)
Physiological processes	Olson (1976); Voigt and Johnson (1976,1977); Horne and Findeisen (1977); Judd and Rose (1977); Neck (1977); Rose and Judd (1982); Olson (1987); Rose et al. (1988)
Disease and parasites	Bowen (1977); Goff and Judd (1981); Schmidt and Fletcher (1983)
Food Habits	Rose and Judd (1982)
Activity and home range	Rose and Judd (1975)
Behavior	Eglis (1962); Weaver (1970)
Demography	Judd and Rose (1983); Bury and Smith (1986)
Distribution	Gunter (1945); Brown (1950); Auffenberg and Franz (1978c); Rose and Judd (1982)

Table 2. Selected publications on the biology of *Gopherus flavomarginatus*.

Ecology	Auffenberg (1969); Morafka et al. (1981); Morafka (1982); Appleton (1986); Bury et al. (1988); Morafka and McCoy (1988); Lieberman and Morafka (1988); Adest et al. (1989a); Morafka (1994); Tom (1994); Germano (1994b)
Morphology	Legler (1959); Legler and Webb (1961); Auffenberg (1976); Auffenberg and Franz (1978a); Bramble (1982); Morafka (1982); Crumly (1994); Germano (1993)
Reproduction	Morafka (1982); Adest et al. (1989a)
Physiological processes	Aguirre et al. (1979); Rose (1983)
Husbandry	Appleton (1980); Adest et al. (1989b)
Food habits	Aguirre et al. (1979)
Activity and home range	Aguirre et al. (1979, 1984); Lindquist and Appleton (1985); Adest et al. (1988); Tom (1994)
Demography	Aguirre et al. (1979); Bury et al. (1988)
Biogeography	Morafka (1988)
Distribution	Auffenberg and Franz (1978d); Morafka (1982); Bury et al. (1988)

Table 3. Selected publications on the biology of *Gopherus polyphemus*.

Ecology	Hubbard (1893); Hallinan (1923); Hansen (1963); Auffenberg (1969); Douglass and Winegarner (1977); Douglass (1978); Dietlein and Franz (1979); Landers (1980); Lohoefner and Lohmeier (1981); Auffenberg and Franz (1982); Lohoefner (1982); Means (1982); Kushlan and Mazzotti (1984); Diemer (1986); Kaczor and Hartnett (1990); Breininger et al. (1991); Wilson (1991); Wilson et al. (1991)
Growth	Goin and Goff (1941); Landers et al. (1982); Germano (1990, 1994b)
Morphology	True (1882); Allen and Neill (1953); Neill and Allen (1957); Spearman (1969); Auffenberg (1976); Auffenberg and Franz (1978a); McRae et al. (1981a); Bramble (1982); McEwan (1982); Palmer and Guillette (1988); Palmer (1989); Crumly (1994); Germano (1993)
Reproduction	Hubbard (1893); De Sola and Abrams (1933); Kenefick (1954); Arata (1958); Auffenberg and Iverson (1979); Iverson (1980); Landers et al. (1980); Linley (1986); Martin (1989); Diemer and Moore (1994); Germano (1994a); Linley and Mushinsky (1994)
Courtship and mating	Auffenberg (1966); Douglass (1976, 1990)
Physiological processes	Jackson et al. (1974); Minnich and Ziegler (1977); Ross (1977); Douglass and Layne (1978); Minnich (1979); Taylor and Jacobson (1982); Bjorndal (1987); Ultsch and Anderson (1986); Linley and Mushinsky (1994)
Burrow commensals	Young and Goff (1939); Brode (1959); Speake (1981); Woodruff (1982); Franz (1986); Jackson and Milstrey (1989); Lips (1991)
Food habits	Garner and Landers (1981); MacDonald and Mushinsky (1988)
Behavior and movement patterns	Brode (1959); Gibbons and Smith (1968); Gourley (1972, 1974, 1984); Douglass and Layne (1978); McRae et al. (1981b); Hailman et al. (1991); Diemer (1992b); Wilson et al. (1994)
Relocation	Diemer and Moler (1982); Lohoefner and Lohmeier (1986); Diemer (1987); Burke (1989a, 1989b); Diemer et al. (1989 and papers within)
Demography	Auffenberg and Iverson (1979); Alford (1980); Wester (1983); Linley (1986); Cox (1989); Diemer (1992a); Mushinsky and McCoy (1994)
Distribution	Auffenberg and Franz (1978e); Sanders (1981); Auffenberg and Franz (1982); Mann (1990)

Table 4. Selected publications on the biology of *Gopherus agassizii.*

Ecology	Grant (1936b, 1946); Woodbury and Hardy (1940, 1948); Loomis and Giest (1964); Burge and Bradley (1976); Burge (1978, 1979, 1980); Bury et al. (1978); Hohman and Ohmart (1978); Barrow (1979); Medica et al. (1980); Sheppard (1981); Reyes Osorio and Bury (1982); Luckenbach (1982); Berry and Turner (1987); Turner et al. (1987a, 1987b); Barrett (1990); Fritts and Jennings (1994); Germano et al. (1994)
Growth	Bogert (1937); Miller (1932, 1955); Grant (1960a); Patterson and Brattstrom (1972); Medica et al. (1975); Jackson et al. (1976, 1978); Patterson (1977, 1978); Turner et al. (1987b); Germano (1988, 1990, 1992, 1994b)
Age determination and longevity	Miller (1932); Woodbury and Hardy (1948); Turner et al. (1987b); Germano (1988, 1992, 1994a)
Morphology	True (1882); Grant (1936a, 1937, 1944, 1960a, 1960b); Miller (1932, 1955); Woodbury and Hardy (1948); Nichols (1953); Shaw (1959); Auffenberg (1976); Auffenberg and Franz (1978a); Jackson et al. (1980); Bramble (1982); Good (1987); Crumly (1994); Germano (1993)
Reproduction	Miller (1955); Nichols (1957); Turner et al. (1981, 1986, 1987b); Luckenbach (1982); Germano (1994a)
Physiological processes	Dantzler and Schmidt-Nielsen (1966); Schmidt-Nielsen and Bentley (1966); McGinnis and Voigt (1971); Voigt (1975); Minnich (1977, 1979); Rosskopf (1980); Nagy and Medica (1986)
Disease and parasites	Harbinson (1937); Fowler (1976); Snipes et al. (1980); Rosskopf et al. (1981); Harper et al. (1982); Snipes and Biberstein (1982); Greene (1986)
Food habits	Burge and Bradley (1976); Hansen et al. (1976); Coombs (1979); Luckenbach (1982); Marlow and Tollestrup (1982); Jarchow (1987); Esque and Peters (1994); Oldemeyer (1994)
Behavioral ecology	Patterson (1971a, 1971b, 1971c); Black (1976); Burge (1977); Barrett and Humphrey (1986); Esque and Peters (1994)
Relocation	Cook et al. (1978); Weber et al. (1979); Berry (1986b)
Effects of human-induced disturbance	Berry (1978); Nicholson (1978); Nicholson et al. (1980); Turner et al. (1981); Nicholson and Humphreys (1981); Luckenbach (1982); Medica et al. (1985); Berry (1986c); Burge (1986); Woodman (1986); Oldemeyer (1994)
Demography	Berry (1976); Burge and Bradley (1976); Burge (1978); Turner et al. (1987b); Esque and Duncan (1989); Germano and Joyner (1989); Berry et al. (1990a, 1990b); Corn (1994)
Distribution	Auffenberg and Franz (1978b); Burge (1979, 1980); Hulse and Middendorf (1979); Karl (1980, 1981); Patterson (1982); Luckenbach (1982); Schneider et al. (1985); Walchuk and deVos (1985); Berry et al. (1986); Collins et al. (1986); Bury et al. (1994); Fritts and Jennings (1994); Germano et al. (1994)

about the desert tortoise is in unpublished reports, sometimes called "gray literature," and is exemplified by a review of recent research on desert tortoises in California (Berry 1986a). Of the 28 citations, 15 (54%) are unpublished reports, 7 (25%) are from the proceedings of The Desert Tortoise Council and one other conference (which were not reviewed by peers), 2 (7%) are government publications, and 4 (14%) are from journals with peer-reviewed papers. Thus, about 61% of the citations are unpublished reports and papers.

Similarly, unpublished reports on the desert tortoise occupy about 1.5 m (depth) of our file cabinet and weigh about 65 kg. These files include neither many recent contract reports nor 1,850 pages of the 1976–86 Proceedings of The Desert Tortoise Council and approximately 650 pages of the 1987–92 proceedings (not yet released). This volume of unpublished literature reflects the verbosity and generally low quality of studies of desert tortoises. Unpublished literature is not unique to desert tortoises and has been criticized in other disciplines, especially in the fisheries science (Collette 1990; Wilbur 1990).

Although several substantial papers appeared in the proceedings of the Desert Tortoise and Gopher Tortoise councils, the overall quality is uneven, and until recently most papers were not subject to reviews by anonymous peers. Also, time to publication is long (often over 5 years), and the date of publication is unclear—for example, the Proceedings of the Desert Tortoise Council from 1982 to the present have a copyright date that is the year of publication and not the years of the symposia.

Although both proceedings are suitable outlets for progress reports and discussions of conservation, we urge that original research be published in established journals and other outlets that solicit reviews of anonymous peers. Recently, The Gopher Tortoise Council decided to publish only a quarterly newsletter, including abstracts from its annual meeting. This is an effective means for disseminating information and discontinuing contributions to the gray literature.

The proliferation of unpublished reports is a disservice to the scientific and wildlife-management communities for several reasons. The trivialization of the literature results in reports that are unobtainable or difficult to secure, which in turn affects timely decisions in management and conservation. Federal and state governments list species as threatened or endangered based on the best available biological information that implies objective research and credible science. However, the gray literature is dominated by economic–political needs, advocacy viewpoints, or immediate cures of issues that can compromise effective long-term conservation of tortoises.

Geographic Coverage

Although important for long-term studies (Rose and Judd 1982; Judd and Rose 1989), most research on the Berlandier's tortoise has been limited to coastal areas of south Texas (Table 1). Parallel research is needed in other parts of the range of the Berlandier's tortoise at inland sites in Texas and Mexico. The distribution of the Berlandier's tortoise in Mexico is unsurveyed, although this area includes over half of the range. This area is important because recent changes in land-use patterns from pastoral to agricultural fields in Mexico may have already eliminated part of the tortoise's range (F. W. Judd, University of Texas-Pan American, Edinburg, Texas, personal communication).

Research on desert tortoises deserves similar criticism because most studies were on populations in creosotebush (*Larrea tridentata*)-scrub habitats of the Mojave Desert (Woodbury and Hardy 1948; Luckenbach 1982; Berry 1986a, 1986b; Berry et al. 1990a). However, this species exists in a wide variety of habitats locally and over its large range (Lowe 1990; Bury et al. 1994; Fritts and Jennings 1994; Germano et al. 1994). Little research has been conducted on populations in the Sonoran Desert, and almost no ecological studies have been done on the desert tortoise in the Sinaloan thornscrub and Sinaloan deciduous woodland in Mexico. As an example of our lack of knowledge, the range of the desert tortoise in Sonora and Sinaloa was recently described in almost 50% more sites than were previously known (Fritts and Jennings 1994).

Information on distributions of the North American tortoises is incomplete. In particular, we recommend thorough surveys of the ranges of the desert tortoise and the Berlandier's tortoise in the Mexican portion. The southernmost range of the desert tortoise in Sinaloa is not known (Patterson 1982; Fritts and Jennings 1994; Germano et al. 1994).

Suggested Research: Approaches and Questions

Estimates of Occurrence and Density

Although much information about the occurrence and relative abundance of tortoises is available (Auffenberg and Franz 1982; Luckenbach 1982; Berry 1986a), the current techniques of estimating population density need a better statistical design and efficient implementation. One of our major concerns is that walking transects is routinely used to estimate densities of desert tortoises (Nicholson 1978; Burge 1979, 1980; Karl 1981; Schneider et al. 1985; Collins et al. 1986), but these techniques yield only relative-abundance data. The results of sampling with linear transects have not been rigorously compared with known populations in varied habitats (e.g., valley, midslope, and rocky hills) or with results of other line–transect methods (Buckland et al. 1993).

Small populations of tortoises may be remnants of formerly larger populations or recent invaders of an area. Furthermore, tortoises may have a small population size or occupy marginal habitat today but not in future years or decades if weather or rainfall patterns change. We need to ask why certain areas have high, moderate, or low densities of tortoises and what determines population size.

Quantifications of habitats, vegetation, and soils that tortoises use are lacking. For example, most studies of population trends in desert tortoises are based on intensive sampling in small plots of about 2.6 km^2 (Berry 1986a, 1990a, 1990b). Because desert tortoises have large home ranges (Luckenbach 1982; Berry 1986a), we suggest that sampling in larger habitats (e.g., 10–20 km^2) and in all habitats (e.g., a valley and adjacent hillsides) with the same level of effort provides greater insight into the biology of the animals. This change may provide larger sample sizes and sufficient young individuals to estimate population sizes and may let investigators meet the assumptions of mark–recapture methods (White et al. 1982; Corn 1994).

Geographic Variation

We need a better understanding of the biology of each species from the major habitat or geographic portions of their ranges. For comparative studies, a minimum of three study sites determines the range and mean of variables. Representative areas can be selected to serve as intensive ecological research foci with an emphasis on year-to-year variation in population features, and animals on these sites need to be followed for 5-year periods or longer to detect environmental variability.

Many study sites for the desert tortoise exist in the Mojave Desert but are revisited at intervals of only 5 or more years (Berry 1990a, 1990b). To complement these sites, we suggest a set of permanent sites in the western Mojave Desert, eastern Mojave Desert, Sonoran Desert, and Sinaloan thornscrub for yearly sampling in representative habitats. Because precipitation patterns are unpredictable in most of these arid habitats, studies of populations must be continuous to assess responses of resident tortoises to environmental fluctuations.

More studies of the gopher tortoise are needed on islands off Florida and in Florida, Alabama, and Georgia and of peripheral populations in Mississippi and South Carolina. Established study sites exist in many of these areas (Douglass and Layne 1978; Lohoefner and Lohmeir 1981; Auffenberg and Franz 1982; Landers et al. 1982; Diemer 1992b; Mushinsky and McCoy 1994), and coordination among researchers and adequate funding are the key for the collection of comparative data and long-term studies.

For sampling the Berlandier's tortoise, sites need to be established in inland Texas and in Mexico. Study sites for the Bolson tortoise exist only in the southern portion of its range, but efforts are under way to expand work into other areas (Morafka and McCoy 1988; Adest et al. 1989a).

Studies of Habitats

Habitat quality and quantified habitat use are basic information for effective management of tortoises and their habitats. Moreover, this information is critical for defining the habitat requirements of the species in the next few decades because of rapid human exploitation in arid habitats.

Most surveys of the desert tortoise in the Mojave Desert were on bajadas (alluvial fans) and valley floors (Woodbury and Hardy 1948; Berry 1986a; Berry et al. 1990b) but not on the mountain slopes where tortoises also occur (Luckenbach 1982; Bury et al. 1994). Desert tortoises favor hills and mountain slopes in the Sonoran Desert (Burge 1980; Lowe 1990; Germano et al. 1994) and in Sinaloan thornscrub (Fritts and Jennings 1994). However, a lack of surveys in hills and on mountains in the Mojave Desert probably has biased our understanding of where tortoises live and how they use their habitats. Thus, we should be cautious in believing that desert tortoises prefer only flats or bajadas in some regions.

We suggest random surveys in all potential habitats, along elevational gradients, and across habitat types to determine how tortoises use resources in different plant communities and ecotones. Equal effort and quantitative information will best answer the question of habitat selectivity by tortoises. Then, in each habitat, the roles of soil and cover types that tortoises need have to be identified.

Life History Traits

Information is needed on the fecundity, longevity, and survivorship of all species, especially of southern populations (Sonoran and Sinaloa) of desert tortoises and inland populations of the Berlandier's tortoise (Texas, Nuevo Leon, and Tamaulipas). Much of the life history of the Bolson tortoise remains unknown. For comparisons across species, research methods must be standardized.

Studies of the fecundity of all species may be patterned after two models: desert tortoises (Turner et al. 1986) and freshwater turtles (Congdon and Gibbons 1990; Gibbons and Greene 1990; Vogt 1990). For the most convincing results, about 30 mature female tortoises have to be equipped with radio transmitters for relocation about every 10 days during the breeding season. Eggs in females can be detected with radiography (Turner et al. 1986; Rose and Judd 1989; Diemer and Moore 1994) or perhaps with sonograms (Kuchling 1989). Radiographing may have to be done for 2–3 months until no more eggs are observed. Besides radiographing mature females, smaller individuals must be radiographed to determine the size and age at which females can first produce eggs. This basic information has not been quantified for any species of tortoise. Sexual maturity has to be better quantified by sizes and ages of males that engage in sexual behavior or by the detection of sperm. Cloacae can be injected with water to flush sperm into vials for later examination in the laboratory.

The ages and longevity of individuals are important for determining population viability. Counts of growth rings are reasonably accurate for aging North American tortoises as old as 20–25 years (Landers et al. 1982; Germano 1988; Zug 1991). Thin scute sections may be useful for aging older individuals (Germano 1992), but this technique and other nondestructive methods of aging living tortoises have not been finalized. Scute rings of most tortoises less than 20 years old can be counted in the field and compared with those of individuals whose ages are known from mark–recapture studies.

Survivorship in wild animal populations is difficult to determine. Large sample sizes are needed to accurately determine rates and patterns of hatchling and juvenile survivorship, but young tortoises are difficult to find in the wild (Luckenbach 1982; Judd and Rose 1983; Berry and Turner 1987; Adest et al. 1989a). Information from prior reports (Berry and Turner 1987) and from reports in this collection (Morafka 1994; Tom 1994; Wilson et al. 1994) indicates that the ecology of hatchlings and small juveniles is markedly different from the ecology of adults—for example, small tortoises are secretive and rarely active away from cover. The absence of reliable techniques to locate juveniles also precludes assessment of age structure and trends in numbers of tortoises in populations.

Several new techniques may increase the captures of young tortoises. Dogs have been used successfully to locate box turtles (*Terrapene carolina*; Schwartz et al. 1984) and may be able to locate young desert tortoises. Intensive surveys at relatively small study sites (4.0–10.8 ha) revealed that juveniles comprised 38–60% of gopher tortoise populations (Diemer and Moore 1994). Furthermore, after young tortoises are located, they can be followed with radiotelemetry for extended periods (Wilson 1991; Tom 1994; Wilson et al. 1994) to obtain much information on their biology.

Analyses of the age and size classes of all captured individuals in an area can identify the population structure (Aguirre et al. 1979; Auffenbreg and Iverson 1979; Judd and Rose 1983; Germano and Joyner 1989; Berry et al. 1990a, 1990b; Diemer 1992a; Germano 1992; Mushinksy and McCoy 1994). Many populations of desert tortoises seem to consist of mostly adults and only few or no juveniles. This structure is sometimes assumed to represent populations with little or no recruitment (Berry 1976, 1986a, 1986b). However, there are alternative explanations for skewed adult-age or size structure in tortoise populations.

A disproportionate number of adults may be due to a subjective division of desert tortoises into general categories (Berry et al. 1990b): juvenile 1, 2; immature 1, 2; subadult; and adult 1, 2. Juvenile and immature categories are transitory and short stages, including only 1 or few years of life. The adult group is large (60–75% of most samples) but also more permanent and has many age or size classes of tortoises (Figure). The adult category spans 20–30 or more years of life because tortoises are long-lived (Woodbury and Hardy 1948; Bury 1982; Gibbons 1990), although adult desert tortoises in some populations may not live as long as earlier thought (Germano 1992, 1994a).

There is a tendency to be concerned about few juveniles and immatures in populations (Berry and Turner 1987; Adest et al. 1989a; Berry et al. 1990b), mostly because they are compared with adults. However, we need to recognize that adult survivorship may be equally or more important for the continuity of a population over the long term. Also, skewed distribution frequencies do not always equal declining populations. In chelonians, mortality is high in hatchlings, moderate to high in juveniles, and low in adults (Bury 1979; Frazer et al. 1990). Adult chelonians often live a long life, and population structures are skewed toward adults (Gibbons 1990).We suspect that recruitment in tortoises may be naturally low and only 3–5% of the total population per year. More likely, we suggest that recruitment is low or nonexistent until there is a combination of favorable factors every few years or perhaps decades. Juvenile cohorts probably occur when for 2 or more years conditions are optimal (e.g., normal to high precipitation), a condition that is probably needed for the survival of eggs, hatchlings, and young. Thus, uneven numbers of cohorts enter the population and in time compensate for adult losses. Such a pattern of survivorship is expected in environments such as deserts where weather is unpredictable and precipitation is spotty and low.

Use of Plants

Although the diets of most species of tortoises (Tables 1–4) have been studied and most consist of annual plants, few investigators examined geographic variation in diet and food selection. Concurrent with food studies of tortoises, we recommend studies of yearly changes in the life histories of tortoises that are related to the production of plants that tortoises eat (Oldemeyer 1994) and the evaluation of nutritional values of food plants (Esque and Peters 1994).

Employment of the Scientific Method

Many studies purport to be—but are not—scientific inquiries because they are unpublished and lack rigor. For example, advocacy groups want

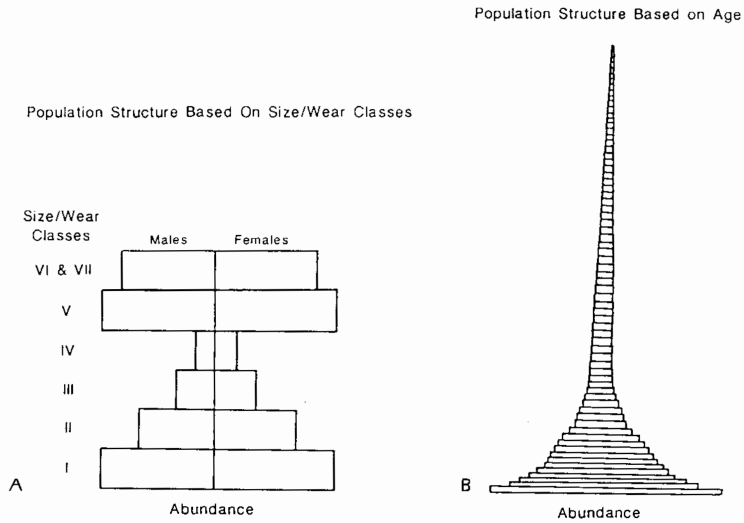

Figure. Comparison of two methods to estimate age and size structure in tortoises: (A) Classes based on shell size and wear categories (I–VII), which tend to emphasize a high proportion of adults in populations; (B) Classes from age (based on count of years on scute annuli), which indicate many increments and greater equability (e.g., the pattern is that of a tall pyramid).

results that support their stance or predetermined ideas. In such cases, we believe that there is no need to pretend that biological studies are being performed. The scientific method is based on rigorous statistical testing of hypotheses, which cannot predict the results of studies (i.e., their outcome is unknown).

The necessity for the application of the scientific method to studies of tortoises seems obvious but needs constant reinforcement. In particular, the desert tortoise is now listed as a threatened species in the Mojave Desert, and many quarters are campaigning for conservation and economic and political interests. Although these pressures are intense, there remains a need for scientific inquiry that is exemplified by objectivity in the study design and by high productivity of peer-reviewed publications. Surveys are important but probably are best performed by contract funding (e.g., consulting firms). Scientific research is better performed by independent investigators (e.g., university professors, research scientists) who test hypotheses.

We found that resource managers generally abhor duplication of effort as a waste of money. Too often, studies are funded for only one area or for one sampling period. However, the replication of studies is a crucial part of the scientific method. For example, three or more study sites are a minimum sample for statistical analyses (i.e., to calculate a range and mean value). The scientific study of animals is an analysis of variation because complex biological systems change over time and space.

Lastly, the employment of the scientific method for management must be addressed. Conservation is wise management of natural resources, and conservation depends on sound biological information. However, the mixing of advocacy with scientific goals may cloud each endeavor. Unlike science that is based on the objective collection and testing of data, ideas, and hypotheses, advocacy is usually biased with emotions and social or economic convictions.

When we recognize them from the outset and clearly state what we do, advocacy roles and objectivity (science) can be compatible human traits or endeavors. Better, separation of these disciplines may be essential for clarity of purpose, sound interpretations, and improved biology and conservation of tortoises and habitats.

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