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A Comparison of GIS and Survey Estimates of Gopher Tortoise Habitat and Numbers of Individuals in Florida

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ABSTRACT. – We compared Geographical Information Systems (GIS) and survey estimates of the amount of gopher tortoise (*Gopherus polyphemus*) habitat and number of individuals on 44 conservation areas in Florida. Estimates of total amount of habitat on conservation areas ≥ 20 ha in size differed by about 12%, with survey estimates ("realized habitat") unexpectedly larger than GIS estimates ("potential habitat"). This difference resulted mostly from the subjective evaluation of habitat suitability employed in the GIS method. Estimates of total number of individuals on conservation areas ≥ 20 ha in size differed by as much as 46%. This difference resulted mostly from the different ways in which numbers of individuals are estimated in the GIS and survey methods and the different ways in which numbers of individuals are calculated from numbers of burrows. Despite the differences between GIS and survey estimates, the GIS method produced important information about potential high quality gopher tortoise habitat. This information helps to identify locations where innovative management techniques might allow the gopher tortoise to expand its distribution, and to inventory suitable, but currently vacant, habitat (because of population declines resulting from upper respiratory tract disease, for example) for future re-establishment efforts.

KEY WORDS. – Reptilia; Testudines; Testudinidae; *Gopherus polyphemus*; tortoise; demography; conservation areas; Geographical Information Systems (GIS); habitat; numbers of individuals; surveys; conservation; USA; Florida

An important, yet difficult, task for conservation biologists is documenting the distributions and abundances of rare, threatened, or endangered species, and identifying gaps in their protection. Geographical Information Systems (GIS) is an increasingly-important tool for dealing with this task (see Spellerberg, 1991; Heyer et al., 1994; Miller, 1994; Edwards et al., 1996; Andersen et al., 2000). For example, GIS has been used to identify current gaps in Florida's conservation system and to develop habitat conservation strategies for the future (Cox et al., 1994). To help to develop conservation strategies for upland habitats in Florida, GIS data on gopher tortoise, *Gopherus polyphemus*, habitat were employed to estimate the number of patches of habitat on conservation areas that could support relatively large populations (Cox et al., 1994). Ultimately, 93 conservation areas were identified that collectively were thought to provide "the minimum level of habitat protection required to maintain gopher tortoises" (Cox et al., 1994).

Despite the technical sophistication of GIS habitat estimates, sufficient external validation of them is often lacking. For example, neither the degree to which gopher tortoises actually occupy patches of habitat that have been identified by GIS nor the actual density of individuals are known with certainty. If degree of occupancy and/or density actually is much less than the estimates, then statements such as the one above, by Cox et al.(1994), might be too optimistic. Here, we compare GIS and survey estimates of amount of gopher tortoise habitat and number of individuals on 44 conservation areas in Florida. Our working hypothesis is that the GIS estimate of total area will be substantially greater than the survey estimate, because the GIS method indicates the amount of "potential habitat" and the survey method indicates the amount of "realized habitat" (see Edwards et al., 1996).

METHODS

GIS Estimates of Habitat. — Data on potential habitat were gathered by two GIS methods. The first was that employed by Cox et al. (1994). Xeric land-cover types (sandhill, oak scrub, sand pine scrub) and other land-cover types underlain by xeric soils (pineland, dry prairie, mixed-hardwood pine) were isolated to form an initial map of potential gopher tortoise habitat. The initial map was refined by identifying contiguous patches of potential habitat ≥ 20 ha and smaller patches within 60 m of the contiguous patches. An area of 10–20 ha may be the minimum area required to support a gopher tortoise population of 40–50 individuals, which, based on population viability estimates, should be the smallest population size generally considered for habitat protection efforts (Cox et al., 1987). The method was then used to identify conservation areas with enough potential habitat to support a population of 200 individuals. If the density of individuals is taken as 3/ha (Cox et al., 1987), then an area of 67 ha would be necessary to support such a population.

The second method was a new method employed by one of us (Stys). We shall present this method in considerable detail for those unfamiliar with the use of GIS in estimating potential habitat. GIS was used to manipulate and analyze three principal data sets: land cover, soils, and natural vegetation. The presence or absence of many species, including the gopher tortoise, is closely related to these three habitat components. Other GIS data sets used in the method included county boundaries, conservation lands, and land use/land cover files. United States Geological Survey (USGS) Digital Line Graph vector coverages, digitized from 1:100,000 scale quadrangle maps for the state of Florida, were used for political boundaries. A statewide map of conservation areas was obtained from Florida Natural Areas Inventory, the unit of The Nature Conservancy responsible for maintaining Florida's natural heritage database. Boundaries of conservation lands typically are digitized from 1:24,000 scale USGS topographic maps. Land use/land cover data, classified using the Florida Land Use, Cover, and forms Classification System (FLUCCS) (Florida Department of Transportation, 1985), were obtained from each of the State's Water Management Districts, converted to 100 m pixel grids and merged to create a statewide raster map of land use/land cover. ArcView GIS v.3.1 with the Spatial Analyst extension was used for all spatial analyses. Each of the data layers was converted to raster format (i.e., grid) with 100 m pixels for all spatial analyses.

The primary land cover data set used was the Florida Land Cover Map (FLCM, Kautz et al., 1993). The FLCM was developed from Landsat Thematic Mapper imagery collected from 1985 to 1989. Of the 22 land cover classes identified, 17 are "natural" vegetation types, 1 is water, and the remaining 4 represent mostly "disturbed" lands. A more detailed description of the development of the FLCM is found in Kautz et al. (1993). Classes representing xeric community types were extracted from the FLCM and saved as the Xeric Communities Map (XCM). Xeric land cover classes included on the map were coastal strand, sand pine scrub, sandhill, and xeric oak scrub. Dry prairie, pineland, mixed hardwood pine forests, and shrub and brushland were individually extracted from the FLCM to produce four additional maps. These maps were then refined further according to analyses described below.

Land cover classes selected from the FLCM (Kautz et al., 1993) were further refined in an attempt to eliminate other land uses of doubtful or highly variable value as gopher tortoise habitat. The XCM was refined using the FLUCCS data, by retaining only those portions of xeric communities that were identified as beaches other than swimming, coastal scrub, shrub and brushland, pine flatwoods, longleaf pine-xeric oak, woodland pasture, sand pine, xeric oak, unimproved pasture, other shrubs and brush, pine mesic oak, upland coniferous forests, oak-pine-hickory, temperate hardwoods, sand live oak, upland hardwood forest, hardwood conifer mixed, sand other than beaches, and palmetto prairies. The individual maps of dry prairie, pineland, mixed hardwood-pine forests, and shrub and brushland also were further refined using the FLUCCS data. Lands within these four cover types were retained if they were identified as shrub and brushland, pine flatwoods, longleaf pine-xeric oak, woodland pasture, sand pine, xeric oak, unimproved pasture, other shrubs and brush, electrical power transmission lines, coastal scrub, upland coniferous forests, pine mesic oak, upland hardwood forests, oak-pine-hickory, temperate hardwoods, sand live oak, hardwood conifer mixed, and palmetto prairies. The resultant map of dry prairie was added to the XCM. Pineland land cover that was identified as pine flatwoods by the FLUCCS data was extracted and retained. The resultant map of pine flatwoods also was added to the XCM. All other pine classes, mixed hardwood-pine forest, and shrub and brushland were analyzed further.

Further analysis of the pine, mixed hardwood-pine forest, and shrub and brushland involved the creation of a Xeric Soils and Habitat Map (XSHM), based on soils and natural vegetation. Detailed soils maps (SSURGO, US Dept. of Agriculture, 1994) were available for 52 of the 67 counties. The remaining 15 counties were assessed using generalized soils maps (STATSGO, US Dept. of Agriculture, 1991). Using the extensive databases provided with the SSURGO and STATSGO soils maps, we extracted lands characterized as xeric, well-drained soils. We extracted them by isolating polygons characterized as extremely well-drained or well-drained and having an annual flood rate of none or rare. The subset of polygons obtained was reduced further by selecting only those lands that had $\geq$ 1.22 m minimum depth to water table, a 1.52 m minimum depth to the upper boundary of a cemented pan, and were in either Class A or Class B hydrologic group. The sum of all these steps was a data set that represented soils that have high to moderate infiltration rates, are deep to moderately deep, are excessively to moderately well drained, and have 0–5% chances of flooding annually.

To identify xeric natural vegetation, we employed the General Map of Natural Vegetation (GMNV, Davis, 1967). This map was presumed to reflect the vegetation types of pre-settlement Florida. The GMNV, as modified by Wilson Crumpaker and Dennis Hardin, contains 22 major vegetation types. Vegetation types that may contain potential gopher tortoise habitat were identified. The vegetation types included forests of longleaf pine and xerophytic oaks, north Florida coastal strand, south Florida coastal strand, upland hardwood forests, and sand pine scrub forests. These five types were merged together to form a data set representing potential xeric habitats.

Spatial Analyst was used to combine the soils and natural vegetation data sets into the Xeric Soils and Habitat Map (XSHM). Spatial Analyst was then used to refine the maps of pine, mixed hardwood-pine forest, and shrub and brushland created earlier. Only those lands identified in the XSHM were retained. The results were added to the Xeric Communities Map (XCM) to create a final map of potential gopher tortoise habitat (Fig. 1). The map of conservation lands was then used to tabulate area of potential gopher tortoise habitat within conservation areas.

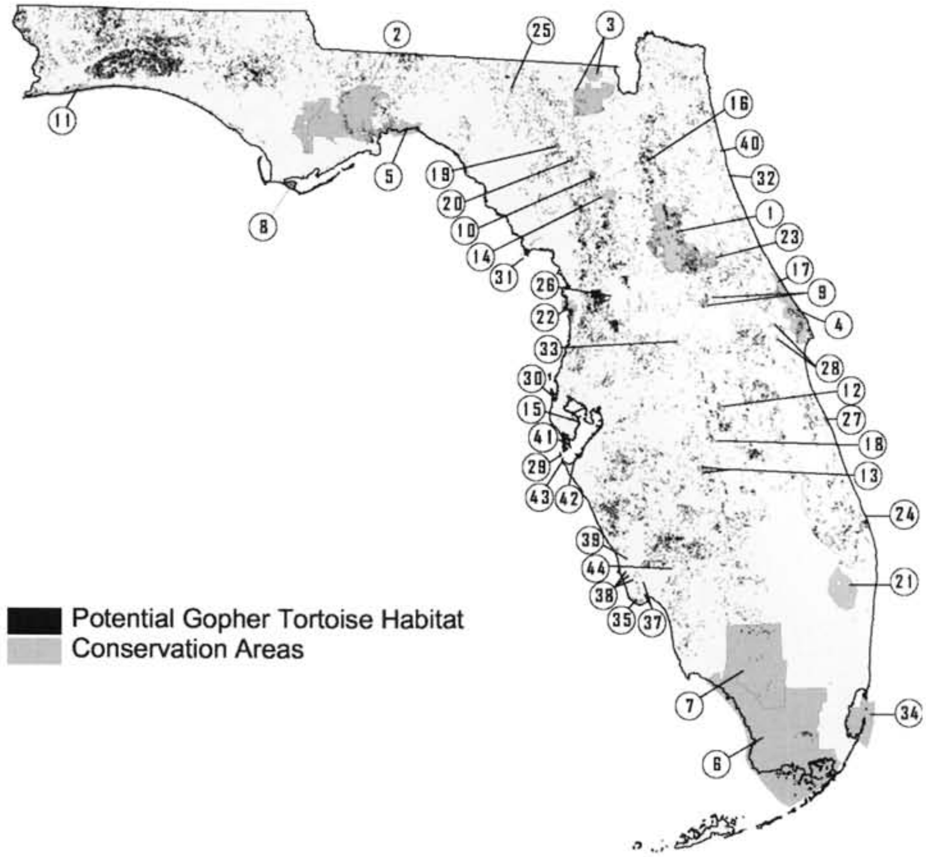

Figure 1. Potential gopher tortoise habitat identified by GIS (method of Stys) and conservation areas surveyed (McCoy and Mushinsky 1988, 1991). Conservation areas are designated by the corresponding numbers in Table 1.

The initial map of potential gopher tortoise habitat on conservation lands was refined by identifying contiguous patches of habitat and eliminating patches < 20 ha in size. During the analysis process all habitat types were considered equal (i.e., a contiguous patch could be composed of a variety of habitat types) and diagonal pixels were included. The political boundaries of the conservation lands were used in determining which patches to eliminate. For example, if two adjacent parcels of conservation land shared a single contiguous patch of habitat and neither one of the conservation parcels contained ≥ 20 ha within its own boundaries, then that patch was eliminated.

Limitations of available data bases used in GIS modeling could be responsible, in part, for any difference that might be found between GIS and survey estimates of gopher tortoise habitat. First, the amount of potential gopher tortoise habitat in the northwest Florida panhandle may be over-represented. Some potential habitat identified there is known, or suspected, to have few, if any, individuals, possibly because of past over-harvest (Auffenberg and Franz, 1982) and declining habitat quality, resulting from the absence of fire and the presence of off-site plantings of sand pine (Diemer, 1986). Second, the amount of potential habitat in south-central and south Florida may be under-represented. Dry prairie and pine flatwoods cover types, which are used by the gopher tortoise in these regions, often are not retained as xeric communities. Third, the use of the FLCM, STATSGO, SSURGO, and GMNV to identify potential habitat may provide under-estimates of potential gopher tortoise habitat, in general. Because the method stressed xeric communities, the estimates are likely to be a more accurate depiction of potential habitat in xeric communities (with the exception of dry prairie and south Florida pine flatwoods) than in other communities. For example, the gopher tortoise is known to occur currently on several habitat types intentionally not included in the estimates, such as many of the disturbed habitat types. Fourth, the method may fail to reveal some very small patches of habitat on conservation areas that have gopher tortoise populations of at least 50 individuals.

Survey Estimates of Habitat. — Data on precise locations of populations and numbers of active and inactive burrows for 44 conservation areas were available from two previous studies (McCoy and Mushinsky, 1988, 1991) (Fig. 1). These survey data were gathered in 1986–90, at almost exactly the same time as the satellite data used in the GIS methods. Each of the areas first was searched thoroughly for burrows, and then gopher tortoise habitat was estimated by one of two methods. For relatively large and intermediate-sized conservation areas (supporting more than 100 burrows), we took a series of 7 m wide transects, that were either standard (50 m, 150 m) or variable in length. Examination of the entire width of the transect required three persons walking abreast. We noted any burrows directly on a transect or in its vicinity. The positions of transects with evidence of occupancy were marked on a map, and the positions of burrows marked on the transects. An estimate of the extent of habitat was derived by connecting the peripheral burrows and then determining the area encompassed. Because many of these relatively large conservation areas supported several-to-many isolated groups of burrows, estimation of total extent of habitat often required adding a number of individual estimates together. For relatively small conservation areas (supporting 100 burrows or less), we marked the positions of all burrows with PVC stakes. We located the approximate center of the group of stakes and measured the distance from the center to a line connecting the two nearest peripheral burrows in eight standard directions (N, NE, E, SE, S, SW, W, and NW). An estimate of the extent of gopher tortoise habitat was derived by connecting the resulting eight points and adding together the areas of the resulting eight triangles.

Normal errors associated with surveys could be responsible, in part, for any difference that might be found between GIS and survey estimates of gopher tortoise habitat. First, isolated groups of burrows may be missed. Second, concentrations of burrows may be missed. Third, the area actually used by individuals may be under-estimated. Fourth, important temporal changes in the distribution of gopher tortoise populations may be missed. For example, some conservation areas have increased in size and/or the management of them has improved (e.g., San Felasco Hammock SPr) since the survey data were gathered. Any errors associated with such changes will not affect the comparison of the estimates presented here, however, because the survey data and the satellite data were gathered contemporaneously, but they will affect the relevance of either of the estimates to the current situation.

Estimates of Numbers of Individuals. — The GIS methods yield only an estimate of potential gopher tortoise habitat. Because no empirically derived data on numbers of individuals inhabiting the habitat are available, a standard estimate of density needs to be employed to derive an estimate of potential number of individuals. A reasonable estimate of potential number of individuals can be derived from (ha of habitat) x (3 individuals/ha) (Cox et al., 1994).

The survey method yields both an estimate of gopher tortoise habitat and numbers of burrows simultaneously. The estimates of numbers of individuals can then be derived from the numbers of burrows encountered. The condition of each burrow encountered was recorded as active, inactive, or abandoned. All surveys were made during the warmest months of the year, when gopher tortoises are most active. Active burrows showed evidence of recent tortoise activity, such as footprints around the entrance or scrape-marks within the burrow caused by the plastron abrading the sand. Inactive burrows potentially could be used, but lacked evidence of recent tortoise activity. Abandoned burrows could not be used without excavation, because they were overgrown or damaged. We used two mathematical relationships for deriving the estimates of numbers of individuals from numbers of burrows. The first was 0.614 x (no. active burrows + no. inactive burrows) (Auffenberg and Franz, 1982), and the second was –0.301 + (0.998 x log (no. active burrows)) (McCoy and Mushinsky, 1992a).

The error associated with estimating numbers of individuals, or potential numbers of individuals, could be great. The principal source of error is lack of information on the variation in density of individuals and burrows at locations varying in size or habitat type (see McCoy and Mushinsky, 1988, 1991; Burke, 1989; Breininger et al., 1991; Mushinsky and McCoy, 1994). For example, high, and probably erroneous, estimates of the density of individuals on some of the conservation areas probably result from the extraordinarily high density of active burrows there (e.g., Lake Louisa SP).

RESULTS

Estimates of potential gopher tortoise habitat varied substantially between the two GIS methods. The method used by Cox et al. (1994) yielded 336 conservation areas with ≥ 20 ha of potential habitat, and 265 conservation areas with ≥ 67 ha of potential habitat (data kindly supplied by J.E. Diemer Berish). The method used by Stys yielded 226 conservation areas with ≥ 20 ha of potential habitat, representing 305,171 ha within 1377 patches, and 140 conservation areas with ≥ 67 ha of potential habitat, representing 273,746 ha within 502 patches. Note that the total area of potential habitat decreased by only 10% when patches between 20 and 67 ha were eliminated, but the number of patches (64%) and the number of conservation lands (38%) decreased by a substantially greater percentage. This pattern indicates that the majority of potential habitat on conservation lands is in fairly large, contiguous patches. For example, the 875 patches on 86 conservation lands that were eliminated represent only 31,425 ha while the remaining 502 patches on 140 conservation lands represent 273,746 ha.

GIS estimates of potential gopher tortoise habitat for 44 conservation areas, derived by both methods, are presented in Table 1. These 44 areas were surveyed previously for gopher tortoises, and the results of the surveys also are presented in Table 1. The estimate of total area of gopher tortoise habitat on the conservation areas with ≥ 20 ha of habitat each is 225,419 ha ($n = 30$) (GIS method of Cox et al., 1994), 49,932 ha ($n = 24$) (GIS method of Stys), and 55,812 ha ($n = 23$) (survey method of McCoy and Mushinsky, 1988, 1991). The estimate of total area derived from the GIS method of Stys clearly is nearer that derived from the survey method; however, the difference between the two estimates of total area still is about 12%. The GIS method of Stys failed to reveal 3 conservation areas (Weedon Island SPr, J.N. "Ding" Darling NWR, USF ERA) that, according to the survey method, have gopher tortoise populations (Table 1). Two of those populations are very small, however. The GIS method of Stys also indicated the presence of more than 200 ha of gopher tortoise habitat on 4 conservation areas (Big

Table 1. Estimates of extent of gopher tortoise habitat, including GIS estimates by Cox et al. (1994), GIS estimates by Stys, and survey estimates by McCoy and Mushinsky (M&M) (1988, 1991); and estimates of number and density of individuals, by McCoy and Mushinsky (M&M) (1988, 1991), on 44 conservation areas in Florida. For number and density of individuals, the first figure was derived with the mathematical relationship of McCoy and Mushinsky (M&M) (1992) and the second (in parentheses) with the mathematical relationship of Auffenberg and Franz (A&F) (1982).

Site	Habitat (ha)			Individuals			
	GIS (Cox et al.)	GIS (Stys)	Survey (M&M)	Number (M&M)	Number (A&F)	Density (M&M)	Density (A&F)
1. Ocala NF	113185	24049	10295	14578	(39253)	1.4	(3.8)
2. Appalachicola NF	55226	3147	34150	41065	(82614)	1.2	(2.4)
3. Osceola NF	17581	1515	65	85	(119)	1.3	(1.8)
4. Merritt Island NWR	7596	5683	6977	11257	(56521)	1.6	(8.1)
5. St. Marks NWR	7017	2285	733	1361	(3172)	1.9	(4.3)
6. Everglades NP	5819	3014	85	628	(1137)	7.4	(13.4)
7. Big Cypress NPr	5659	2275	0				
8. St. Vincent NWR	2640	1680	13	9	(13)	0.7	(1.0)
9. Wekiwa Springs SP	1120	801	692	1962	(4769)	2.6	(6.9)
10. S. Felasco Hammock SPr	1107	912	141	189	(360)	1.3	(2.6)
11. Gulf Islands NS	1097	797	0				
12. Lake Kissimmee SP	772	515	81	114	(337)	1.4	(3.0)
13. Highlands Hammock SP	756	568	61	119	(255)	2.0	(4.2)
14. Paynes Prairie SPr	750	232	137	404	(750)	2.9	(5.5)
15. Weedon Island SPr	738	0	3	20	(76)	6.7	(25.3)
16. Gold Head Branch SP	702	581	427	896	(1779)	2.1	(4.2)
17. Canaveral NS	558	392	108	993	(1899)	9.2	(17.6)
18. Lake Arbuckle SP	543	287	347	205	(630)	0.6	(1.8)
19. Ichetucknee Springs SP	516	270	370	966	(2200)	2.6	(5.9)
20. O'Leno/River Rise SP	506	412	675	1678	(3075)	2.5	(4.6)
21. Loxahatchee NWR	394	0	0				
22. Chassahowitzka NWR	277	6	10	57	(93)	5.7	(9.3)
23. Lake Woodruff NWR	179	271	20	45	(77)	2.2	(3.8)
24. Hobe Sound NWR	163	16	0				
25. Suwannee River SP	145	106	113	350	(744)	3.1	(6.6)
26. Fort Cooper SP	140	73	78	478	(980)	6.1	(12.6)
27. Pelican Island NWR	97	0	0				
28. St. Johns NWR	53	6	1	2	(4)	2.0	(4.0)
29. Egmont Key SP	50	3	92	1518	(2128)	16.5	(23.1)
30. Caladesi Island SP	33	28	68	437	(702)	6.4	(10.3)
31. Cedar Keys NWR	12	1	1	10	(14)	10.0	(14.0)
32. Fort Matanzas NM	10	6	11	60	(118)	5.5	(10.7)
33. Lake Louisa SP	8	39	65	1818	(3849)	28.0	(59.2)
34. Biscayne NP	1	0	0				
35. J.N. "Ding" Darling NWR	1	0	10	6	(34)	0.6	(3.4)
36. Univ. South Florida ERA	-	-	32	309	(734)	9.7	(22.9)
37. Matlacha Pass NWR	0	0	0				
38. Pine Island NWR	0	0	0				
39. Island Bay NWR	0	0	0				
40. Castillo de S. Marcos NM	0	0	0				
41. Pinellas NWR	0	0	0				
42. DeSoto NM	0	0	0				
43. Passage Key NWR	0	0	0				
44. Caloosahatchee NWR	0	0	0				

Cypress NPr, St. Vincent NWR, Gulf Islands NS, Lake Woodruff NWR) that, according to the survey method, have very small or no gopher tortoise populations (Table 1). Finally, the GIS method of Stys indicated that the amount of potential gopher tortoise habitat on Appalachicola NF is about an order of magnitude less than the amount of habitat estimated by the survey method (Table 1).

Numbers of individual gopher tortoises typically are calculated differently from GIS and survey estimates of total area of gopher tortoise habitat. For the GIS estimates, employing an overall density of 3 individuals/ha (Cox et al., 1994) yields a total potential number of individuals on the conservation areas with ≥ 20 ha of habitat each of 676,257 individuals (method of Cox et al., 1994) or 149,796 individuals (method of Stys). For the survey estimates, where numbers of active and inactive burrows are known, using the mathematical relationship of McCoy and Mushinsky (1992a) yields a total number of individuals of 81,448 (overall density = 1.46 individuals/ha) and using the mathematical relationship of Auffenberg and Franz (1982) yields a total number of individuals of 208,084 (overall density = 3.73 individuals/ha). Assuming that the actual overall density of individuals is somewhere between 1.46 and 3.73 individuals/ha (McCoy and Mushinsky, 1992a), the difference between the GIS estimate (method of Stys) and the survey estimate is somewhere between 0% and about 46%. If an overall density of 3 individuals were used, then the difference would be about 12%.

DISCUSSION

It is difficult to compare the estimate of total number of individuals based on the survey data with the estimates based on the GIS data, because of the different, although typical, ways that numbers of individuals are estimated from the two kinds of data. It is more reasonable to compare the estimate of potential gopher tortoise habitat based on GIS data to the estimate of habitat based on survey data, because of the obvious fact that some true, albeit unknown, overall density of individuals exists on the conservation areas. The estimate of gopher tortoise habitat based on the survey data (55,812 ha) exceeded the estimate of potential habitat based on GIS data (49,932 ha) by about 12%. The fact that the GIS estimate is lower than the survey estimate, contrary to our working hypothesis, is attributable almost entirely to a single conservation area, Appalachicola NF. The reason for this difference largely is the elimination of the FLUCCS code for pine plantations from the GIS method. Inclusion of the additional habitat on Appalachicola NF would have raised the GIS estimate from 49,932 ha to 80,935 ha.

The example of Appalachicola NF illustrates an important distinction between the GIS and survey methods. In the survey method, gopher tortoise habitat was determined by actual presence of burrows, not by subjective evaluation of habitat suitability, as in the GIS method. The GIS method was aimed at identification of xeric sites assumed to be of relatively high quality. These sites were, in turn, assumed to provide the most likely locations for long-term persistence of gopher tortoise populations. Certain types of habitat, such as pine plantations, were therefore intentionally eliminated, even though they sometimes are used by gopher tortoises, especially in the early stages of succession. Although it would be a difficult, if not impossible, task to map all potential habitat, the increasing marginalization of gopher tortoise habitat distribution, even on many conservation areas (McCoy and Mushinsky, 1992b; Mushinsky and McCoy, 1994), would seem to warrant attempts to do so.

Despite any shortcomings of the GIS method, the estimates of potential high quality gopher tortoise habitat that it produced are important information. The estimates are especially important information for locations where tortoise populations can be shown by surveys to be small or absent, such as on some of the barrier islands in north Florida. In such cases, the information derived from the GIS method identifies locations where innovative management techniques might allow the gopher tortoise to expand its occupancy of potential habitat, thereby creating more realized habitat. Identification of potential high quality habitat may be vital in the face of any population reduction occurring as a result of upper-respiratory tract disease (URTD) of the gopher tortoise (see Diemer Berish et al., 2000). Relatively large populations in high quality habitat on some conservation areas (e.g., Gold Head Branch SP) appear to have been reduced substantially over the past decade (McCoy, Mushinsky, and Lindzey, unpubl.), perhaps as a consequence of URTD. Any high quality habitat that becomes unoccupied because of population reduction needs to be kept in inventory for future re-establishment efforts. Without knowledge of the potential of these unoccupied habitats to support the gopher tortoise, one might assume that they were not suitable, let alone high quality, gopher tortoise habitat.

GIS is a useful tool for developing a quick overview of the status of a species' habitat. It can provide estimates of habitat over a large geographic region that would be virtually impossible to complete with surveys. Results from GIS methods and models should be considered only a good first estimate, however. Sometimes, when no survey data are available, the GIS results provide the only assessment of habitat. In such cases, the results must be viewed conservatively. When survey data are available, they can be used to clarify, correct, and fine-tune the GIS results, as we have illustrated here (see Haila and Margules, 1996).

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LITERATURE CITED

Andersen, M.C., Watts, J.M., Freilich, J.E., Yool, S.R., Wakefield, G.I., McCauley, J.F., and Fahnstock, P.B. 2000. Regression-tree modeling of desert tortoise habitat in the central Mojave Desert. Ecological Applications 10:890-900.

Auffenberg, W. and Franz, R. 1982. The status and distribution of the gopher tortoise (*Gopherus polyphemus*). In: Bury, R.B. (Ed.). North American Tortoises: Conservation and Ecology. U.S. Dept. Int. Fish Wildl. Serv. Wildl. Res. Rep. No.12, pp. 95-126.

Breininger, D.R., Schmalzer, P.A., and Hinkle, C.R. 1991. Estimating occupancy of gopher tortoise (*Gopherus polyphemus*) burrows in coastal scrub and slash pine flatwoods. J. Herpetol. 25(3):317-321.

Burke, R.L. 1989. Burrow-to-tortoise conversion factors: comparison of three gopher tortoise survey techniques. Herp. Rev. 20(4):92-94.

Cox, J., Inkley, D., and Kautz, R. 1987. Ecology and habitat protection needs of gopher tortoise (*Gopherus polyphemus*) populations found on lands slated for large-scale development in Florida. Tallahassee, FL: Florida Game and Fresh Water Fish Commission, Non-Game Wildlife Tech. Report No. 4, 75 pp.

Cox, I., Kautz, R., MacLaughlin, M., and Gilbert, T. 1994. Closing the Gaps in Florida's Wildlife Habitat Conservation System. Tallahassee, FL: Florida Game and Fresh Water Fish Commission, 239 pp.

Davis, I.H. 1967. General Map of Natural Vegetation of Florida. Gainesville: University of Florida, Institute of Food and Agricultural Science, Agricultural Experiment Station, Circular 5-178.

Diemer, J.E. 1986. The ecology and management of the gopher tortoise in the southeastern United States. Herpetologica 42:125-133.

Diemer Berish, J.E., Wendland, L.D., and Gates, C.A. 2000. Distribution and prevalence of upper respiratory disease in gopher tortoises in Florida. J. Herpetol. 34(1):5-12.

Edwards, T.C., Jr., Deshler, E.T., Foster, D., and Moisen, G.G. 1996. Adequacy of wildlife habitat relation models for estimating spatial distributions of terrestrial vertebrates. Conserv. Biol. 10: 263-270.

Florida Department of Transportation. 1985. Florida Land Use, Cover and Forms Classification System. Tallahassee: State Topographic Bureau, Thematic Mapping Section, Procedure 550-010-001-A, 79 pp.

HAILA, Y. AND MARGULES, C.R. 1996. Survey research in conservation biology. Ecography 19:323-331.

HEYER, W.R., DONNELLY, M.A., MCDIARMID, R.W., HAYEK, L.-A., AND FOSTER, M.S. (Eds.). 1994. Measuring and Monitoring Biological Diversity. Standard Methods for Amphibians. Washington, DC: Smithsonian Institution Press, 364 pp.

KAUTZ, R.S., GILBERT, D.T., AND MAULDIN, G.M. 1993. Vegetative cover in Florida based on 1985-1989 Landsat Thematic Mapper imagery. Fl. Scien. 56:135-154.

MCCOY, E.D. AND MUSHINSKY, H.R. 1988. The demography of *Gopherus polyphemus* (Daudin) in relation to size of available habitat. Tallahassee: Florida Game and Fresh Water Fish Commission, Nongame Wildlife Program, 71 pp.

MCCOY, E.D. AND MUSHINSKY, H.R. 1991. A survey of gopher tortoise populations residing on twelve state parks in Florida. Tallahassee: Florida Department of Natural Resources, Office of Land Use Planning and Biological Services, Technical Report 1, 78 pp.

MCCOY, E.D. AND MUSHINSKY, H.R. 1992a. Studying a species in decline: gopher tortoises and the dilemma of "correction factors". Herpetologica 48(4):402-407.

MCCOY, E.D. AND MUSHINSKY, H.R. 1992b. Studying a species in decline: changes in populations of the gopher tortoise on Federal lands in Florida. Florida Scientist 55:116-125.

MILLER, R.I. (Ed.). 1994. Mapping the Diversity of Nature. London: Chapman and Hall, 218 pp.

MUSHINSKY, H.R. AND MCCOY, E.D. 1994. Comparison of gopher tortoise populations on islands and on the mainland in Florida. In: Bury, R.B. and Germano, D.J. (Eds.). Biology of North American Tortoises. Fish and Wildlife Research 13:39-47.

SPELLERBERG, I.F. 1991. Monitoring Ecological Change. Cambridge: Cambridge University Press, 334 pp.

U.S. DEPARTMENT OF AGRICULTURE. 1991. State Soil Geographic Database (STATSGO): Data User Guide. Lincoln, Nebraska: Soil Conservation Service, National Soil Survey Center.

U.S. DEPARTMENT OF AGRICULTURE. 1994. Soil Survey Geographic Database (SSURGO): Data Use Information. Lincoln, Nebraska: Soil Conservation Service, National Soil Survey Center.

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