Conservation Biology

Contributed Paper

Evaluation of Local Ecological Knowledge as a Method for Collecting Extensive Data on Animal Abundance

JOSÉ DANIEL ANADÓN,*† ANDRÉS GIMÉNEZ,* RUBÉN BALLESTAR,* AND IRENE PÉREZ*

*Área de Ecología, Departamento de Biología Aplicada, Universidad Miguel Hernández, Edif. Torreblanca, Campus de Elche, Avda. Universidad s/n, Elche, 03202 Alicante, Spain

Abstract: *The use of local ecological knowledge (LEK) has been advocated for biodiversity monitoring and management. To date, however, it has been underused in studying wild populations of animals and, particularly, in obtaining quantitative abundance estimates. We evaluated LEK as a tool for collecting extensive data on local animal abundance and population trends. We interviewed shepherds in southeastern Spain, asking them to estimate the local abundance of the terrestrial tortoise* Testudo graeca*. We quantified reliability of abundance estimates derived from interviews by comparing them with those obtained from standard field-sampling protocols (distance sampling). We also explored the complementarity of these 2 approaches. LEK provided high-quality and low-cost information about both distribution and abundance of* T. graeca*. Interviews with shepherds yielded abundance estimates in a much wider range than linear transects, which only detected the species in the upper two-thirds of its abundance range. Abundance estimates from both methodologies showed a close relationship. Analysis of confidence intervals indicated local knowledge could be used to estimate mean local abundances and to detect mean population trends. A cost analysis determined that the information derived from LEK was 100 times cheaper than that obtained through linear-transect surveys. Our results should further the use of LEK as a standard tool for sampling the quantitative abundance of a great variety of taxa, particularly when population densities are low and traditional sampling methods are expensive or difficult to implement.*

Keywords: animal abundance, cost-efficiency, distance sampling, local ecological knowledge, terrestrial tortoises, *Testudo graeca*

Evaluación del Conocimiento Ecológico Local como Método para Recolectar Datos Extensivos sobre la Abundancia Animal

Resumen: *El uso de conocimiento ecológico local (CEL) ha sido recomendado para el monitoreo y manejo de la biodiversidad. Sin embargo, a la fecha, se ha subutilizado en el estudio de poblaciones silvestres de animales y, particularmente, en la obtención de estimaciones cuantitativas de la abundancia. Evaluamos CEL como una herramienta para la obtención de datos extensivos sobre la abundancia local de animales y tendencias poblacionales. Entrevistamos pastores en el sureste de España, les pedimos que estimaran la abundancia local de la tortuga terrestre* Testudo graeca*. Cuantificamos la confiabilidad de las estimaciones de abundancia comparándolas con las obtenidas con protocolos estándares de muestreo de campo (muestreo distancia). También exploramos la complementariedad de estos dos métodos. El conocimiento local proporcionó información de alta calidad y bajo costo sobre la distribución y abundancia de* T. graeca*. Las entrevistas con pastores aportaron estimaciones de abundancia en un rango mucho más amplio que los transectos lineales, que solo detectaron a la especies en dos terceras partes de su rango de abundancia.*

†*Current address: Department of Ecological Modelling, UFZ—Helmholtz Centre for Environmental Research, Permoserstrasse 15, 04318 Leipzig, Germany, email jdanadon@umh.es*
Paper submitted March 6, 2008; revised manuscript accepted October 2, 2008.

Conservation Biology, Volume 23, No. 3, 617–625

DOI: 10.1111/j.1523-1739.2008.01145.x

Las estimaciones de abundancia de los dos métodos mostraron una relación cercana. El análisis de los intervalos de confianza indicó que el conocimiento local puede ser usado para estimar abundancias locales promedio y para detectar tendencias poblacionales promedio. Un análisis de costo determinó que la información derivada de CEL fue 100 veces más barata que la obtenida mediante muestreos en transectos lineales. Nuestros resultados deberían promover el uso de CEL como una herramienta estándar para el muestreo de la abundancia cuantitativa de una gran variedad de taxa, particularmente cuando las densidades poblacionales son bajas y los métodos de muestreo tradicionales son costosos o difíciles de poner en práctica.

Palabras Clave: abundancia animal, conocimiento ecológico local, costo-eficiencia, muestreo distancia, *Testudo graeca*, tortugas terrestres

Introduction

The distribution and abundance of species are critical parameters in ecology and conservation. In general, however, their estimation is highly time-consuming and requires extensive funding, and can even prove impossible at times. It has been proposed that the knowledge of local people may yield biological information relevant to conservation efforts (Huntington 2000; Folke 2004). Local people's knowledge of abundance and distribution of species is usually gained through individuals' observations over their lifetimes, and this knowledge is not handed down through generations (Gilchrist et al. 2005). This type of knowledge is called local ecological knowledge (LEK), and it is different from traditional ecological knowledge (TEK). Traditional ecological knowledge can be defined as a cumulative body of knowledge, practice, and belief that pertains to the relationship of living beings (including humans) with one another and with their environment, and it evolves from adaptive processes and is handed down through generations (Gadgil et al. 1993; Berkes et al. 2000). Local ecological knowledge has been used to obtain information on the presence or qualitative abundance of species (e.g., Leedy 1949; Zimmerer 1991; Vaughan et al. 2003; Moller et al. 2004) and on qualitative population trends (Ferguson et al. 1998; Mallory et al. 2003). It has seldom been used to obtain quantitative estimates of abundance or population trends (but see Gilchrist et al. 2005; Lozano-Montes et al. 2008).

Rigorous testing of LEK is necessary prior to its incorporation into management plans (Gilchrist et al. 2005). For that reason, there is an increasing interest in evaluating LEK and TEK as a source of information on different aspects of biological or socioecological systems such as land-cover change (Chalmers & Fabricius 2007), animal harvesting (Jones et al. 2008), geographical mapping (McKenna et al. 2008), and animal-condition indices (Lyver & Gunn 2004). Information about species abundance derived from LEK has rarely been quantitatively evaluated by comparing it with standard scientific protocols (but see Poizat & Baran 1997; Gilchrist et al. 2005; Lozano-Montes et al. 2008) and by assessing the uncertainty of its predictions.

We quantitatively evaluated LEK as a source of information about the distribution and abundance of the threatened spur-thighed tortoise (*Testudo graeca*) of southeastern Spain. Three aspects of the ecology of terrestrial tortoises make surveys of them costly. First, terrestrial tortoises are only detectable during brief periods of time because of their restricted daily and seasonal activity patterns. Second, detection indexes exhibit high interannual variability because activity patterns of tortoises are strongly influenced by annual climatic conditions (Freilich et al. 2000). Finally, tortoises in the wild present a wide abundance range, including natural populations with very low densities. To date, 2 methods have been used to estimate the absolute abundance of terrestrial tortoises: capture–recapture and distance sampling (Anderson et al. 2001; Freilich et al. 2005). Nevertheless, both methods are time-consuming and economically costly and require a reasonably large sample size to yield reliable estimates, which is a problem when dealing with low-density populations (Averill-Murray & Averill-Murray 2005; Freilich et al. 2005). Given these difficulties, alternative standardized methodologies for the sampling of terrestrial tortoises are being devised and tested (e.g., trained dogs; Cablk & Heaton 2006). Local ecological knowledge has been used to study the distribution of terrestrial tortoises, usually as an initial exploratory method to obtain data on presence (e.g., Lambert 1983, Smith et al. 1999) and, more rarely, on estimates of qualitative abundance (Beshkov 1993).

Our objective was to evaluate LEK as a method for collecting reliable, extensive animal distribution and abundance data. Toward this purpose, we characterized the abundance structure of the distribution range of *T. graeca* by means of LEK. We then evaluated the information derived from LEK by comparing it with data derived from more standard scientific methods of field sampling. In particular, we explored the ability of LEK to detect population trends and, thus, its potential as a tool in monitoring programs. It has been suggested that LEK-derived information is complementary to that obtained from more standard scientific methods (Moller et al. 2004). We linked the information from these methodologies by showing how these approaches could be mixed for use in the study of the ecology of populations.

Methods

Interviews with Shepherds

Given the variety of all possible subjects covered by LEK, there are no closed-protocol procedures that are used to collect such information, but there are general guidelines and examples that have to be adapted to the target case study (e.g., Hungtinton 2000; Usher 2000; Davis & Wagner 2003). We interviewed shepherds in the province of Almeria (Spain) about their encounters with *T. graeca* in the wild to assess the distribution and abundance of this species. Defining a target group of "experts" is fundamental when exploring LEK (Davis & Wagner 2003). We selected shepherds from among the local inhabitants because they cover the same area on a daily basis for years and thus are probably the group of people with the most contact with local wildlife. Their unconscious sampling effort is easy to measure, and thus it is possible to standardize it. Standardization of the sampling effort would be difficult with other local groups whose activities in terms of both space and time would be much more irregular (e.g., farmers or hunters). We conducted semidirect personal interviews with the shepherds (Huntington 1998). An interviewer led the interviewee to target questions, but allowed the interviewee to talk about any issue.

We divided the distribution range of *T. graeca* (approximately 1500 km^2) plus a buffer area into quadrats of 20 km^2 and attempted to interview 2 shepherds who frequented each quadrat. Shepherds were interviewed in the field during their normal activity. We asked shepherds what area they covered (and transformed the area to UTM cells of 1 × 1 km), the time they have spent shepherding on each cell, and about the presence and abundance of tortoises in each cell. The time spent per cell was characterized by the number of years, months per year, days per week, and hours per day shepherds had herded in the cell. We used the following questions to characterize presence of tortoises: Have you ever seen a tortoise? If you have seen a tortoise, how long has it been since you saw it? If, according to the interviewee, tortoises were present in a cell, to determine abundance we asked: Every how many years do you see a tortoise on average (YT)? How many tortoises do you see in 1 year on average (TY)? and What is the maximum number of tortoises you have seen in 1 day (TD)?

Of the data collected from interviews, we used only that which described the current distribution and abundance status. We considered information referring to the last 10 years as current; thus, the time scale we selected was a decade. We standardized the data by sampling effort. We defined sampling effort for a given shepherd and cell as the time spent by that shepherd in that cell. Tortoises were considered absent from a cell if no tortoise had been detected after the cell had been shepherded for at least 10 consecutive springs, irrespective of daily shepherding intensity or the cell had been shepherded for 6–10 years of the last decade under maximum shepherding intensity. We considered tortoises present in a cell if a shepherd had seen at least one tortoise in that cell within the last decade. For our abundance estimates, we considered only cells that had been subjected to at least 3 years of maximum-intensity shepherding.

We converted the indices of abundance (YT, TY, and TD) into a single index: number of tortoises seen in 1 year on average multiplied by 10 (TY10). The conversion of YT and TY into TY10 was direct ($TY * 10 = TY10$ and $10/YT = TY10$). To convert the index of daily abundance (TD), we first converted TD into TY. For this purpose, we used linear regression to estimate the relationship between the 2 indices in those cells in which both indices were obtained. Then we used this estimated relationship to perform the conversion.

Distance Sampling

In a selection of cells where tortoises were detected by shepherds, we estimated the absolute abundance of the tortoise with analysis of linear-distance sampling (Buckland et al. 2001). Linear transects were surveyed during the season and hours of maximum activity of the species (midmorning in spring; Pérez et al. 2002). Three people walked parallel to each other along a given transect, yielding 3 replicate samples per transect. Field workers maintained a lateral distance of at least 20 m from each other so that the samples within each transect could be considered independent for statistical purposes. Each cell was sampled 3 times throughout spring. Transects took at least 3 hours to walk and were registered with a GPS. Distance analyses were carried out in Distance 4.0 software (Thomas et al. 2004). In analysis of distance sampling, probability of detection in the center of the transect has to be 1. When working with terrestrial tortoises, this assumption cannot be met because only active tortoises can be detected and only a fraction of all tortoises are active in a given day. To estimate the fraction of tortoises that were active in the transects, we radio-tracked 44 tortoises over a 2-year period in 4 localities along the species distribution range. Tortoises were located for 2 consecutive weeks in every 3 weeks. The mean percentage of tortoises active on spring days was taken as the detection value in the center of the transect (Freilich et al. 2000).

Agreement between LEK and Distance-Sampling Descriptors

To compare the usefulness of LEK and linear sampling when studying animal distributions, species detection (0, no tortoises detected in linear samplings; 1, tortoises detected in linear samplings) was modeled using the

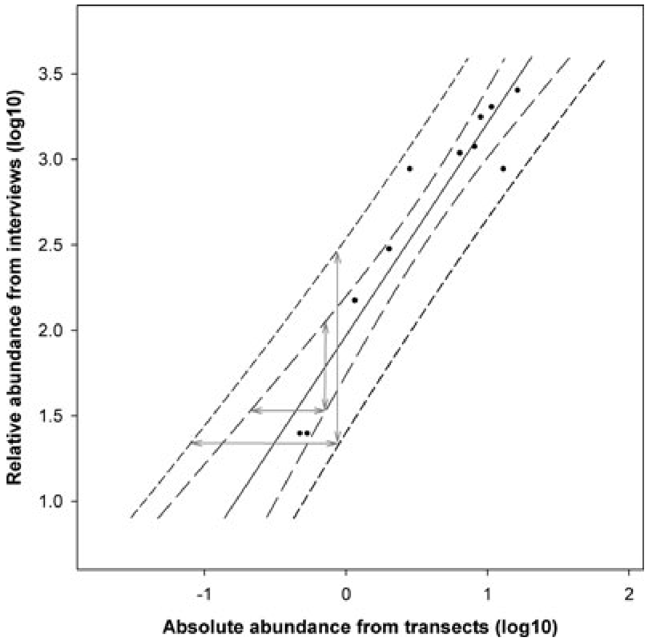

Figure 1. Calibration of the relative abundance index TY10 (number of tortoises seen in a year on average multiplied by 10) obtained from local knowledge with the absolute abundance index (tortoises per hectare) obtained with distance sampling. The regression line (continuous) and the estimation (long-dashed lines, internal) and prediction (short-dashed lines, external) intervals are shown. The lines with arrows indicate the 2 parameters used to describe these 2 confidence intervals (confidence interval of the estimation or prediction [horizontal lines] and the needed difference between the 2 values of TY10 to yield nonoverlapping estimates or predictions of absolute abundance [vertical lines]).

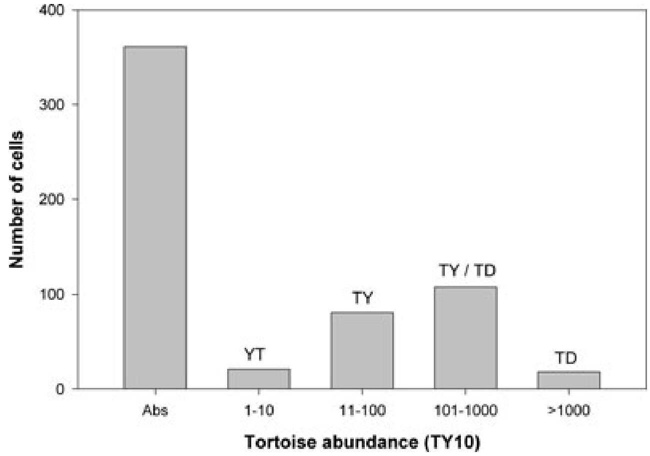

Figure 2. Number of cells with information about abundance of tortoises obtained from interviews with shepherds (TY10, number of tortoises seen in 1 year on average multiplied by 10). The abundance index used in each abundance class is indicated at the top of the bars (YT, number of years on average needed by a shepherd to see one tortoise; TY, number of tortoises seen in a year by a shepherd on average; TD, maximum number of tortoises seen in a day by a shepherd, see Methods).

relative abundance index TY10 as an independent variable in generalized linear models (GLM; McCullagh & Nelder 1987).

We assessed the agreement between the relative abundance index obtained in interviews with shepherds (TY10) and the absolute abundance index obtained with distance sampling in an inverse linear regression (calibration). The uncertainty of estimates of abundance obtained from local knowledge and the shepherds' ability to detect population trends was assessed by calculating the 95% confidence and prediction intervals of the calibration (Draper & Smith 1998). Confidence intervals of the calibration equaled the confidence intervals for an estimate of logAA, given a mean value of logTY10 from a group of localities. Prediction intervals of the calibration equaled the confidence intervals for one estimate of logAA, given one value of logTY10 from just one locality. These confidence intervals were described by the horizontal distance between the interval limits, whose value equaled the confidence interval of the estimation, and the vertical distance between the interval limits, whose value equaled the necessary difference between 2 values of TY10 so that they yielded estimates of AA that did not overlap (Fig. 1). For a given locality or group of localities, this was the distance needed between 2 estimates of abundance to detect population trends.

To explore the complementary nature of the indices obtained by means of LEK and standard sampling protocols, we linked abundance indices derived from LEK with those from field transects.

Cost Analysis

To compare the cost of both methodologies, we estimated distance traveled and field journeys per sampled location (1 × 1 km cell) and considered sampling effort was 1 year for field transects (9 transects).

Results

We conducted 172 interviews with shepherds and obtained information about tortoise distribution or abundance in 985 cells. Abundance was assessed in 595 cells, 360 of which had no tortoises and 235 of which had at least 1 tortoise detected in the last 10 years. Annual abundance index (TY) and the daily abundance index (TD) showed a close relationship (R^2 = 85%, TY= −5.9071 + 9.2016 ∗ TD). The unified abundance index (TY10)

Table 1. Absolute abundance (AA) values of *Testudo graeca* and their estimation and prediction confidence intervals for different values of the relative abundance obtained from interviews with shepherds (TY10).

Interviews			*Estimation (95% CI)*[a,b]		*Prediction (95% CI)*[a,b]		*Width (95% CI)*	
logTY10	*TY10*[c]	*AA*	*min*	*max*	*min*	*max*	*estimation*	*prediction*
1.0[d]	10	0.17	0.06	0.32	0.04	0.50	0.26	0.46
1.5	32	0.42	0.19	0.69	0.11	1.17	0.50	1.06
2.0	100	1.05	0.63	1.51	0.33	2.88	0.88	2.55
2.5	316	2.66	1.91	3.55	0.93	7.41	1.64	6.48
3.0	1000	6.73	5.01	9.77	2.45	19.95	4.76	17.50
3.5	3162	16.98	11.48	30.20	6.17	56.23	18.72	50.07

[a]*Absolute abundance and confidence intervals (CI) are expressed as tortoises per hectare.*
[b]*For an interpretation of the estimation and prediction intervals, see Methods.*
[c]*Relative abundance obtained from interviews with shepherds (TY10) expressed as tortoises seen in a year on average multiplied by 10.*
[d]*Abundance class outside the calibration range.*

ranged from 0 to 2450; this last value corresponded to a cell in which TD was between 20 and 25 tortoises per day. The most frequent logarithmic abundance class was where 100 < TY10 < 1000 (Fig. 2). This abundance class ranged from locations where shepherds saw 10 tortoises per year on average (and a maximum of 2 tortoises in 1 day) to locations where shepherds saw a maximum of 10 tortoises in 1 day.

We sampled 17, 1 × 1 km cells with linear transects. There were 6 cells where no tortoises were encountered. In the localities with tortoise encounters, the mean encounter rate was 0.45 tortoises per person and hour (range = 0.03–1.24). Detectability in the center of the transect, estimated through radio tracking, was 0.36. Absolute abundances in localities with encounters of tortoises ranged from 0.81 to 15.55 tortoises hectare. The accuracy of these estimates varied largely among localities, depending on the number of tortoises observed. In localities with encounter rates >0.4 tortoises per hour and observer that corresponded approximately to populations with more than 6 tortoises per hectare, the coefficient of variation (CV) ranged from 19 to 35%. Nevertheless, in localities with fewer observed tortoises and lower encounter rates, CV values were larger, ranging from 49 to 101%.

Table 2. Three examples of pairs of values of relative abundance (TY10) of *Testudo graeca* for groups of populations that yielded estimates of absolute abundance (AA) with nonoverlapped confidence intervals.

LogTY10	*Description*	*AA*[a]	*95% CI*[a]
0.9	8 tortoises in 10 years	0.14[b]	0.05–0.27
1.63	4 tortoises/year	0.54	0.27–0.83
2.0	10 tortoises/year or maximum 1 or 2 tortoises/day	1.05	0.63–1.51
2.39	25 tortoises/year or maximum 3 tortoises/day	2.19	1.51–2.95
3.0	maximum 10 tortoises/day	6.76	5.01–9.77
3.4	maximum 25 tortoises/day	14.12	9.77–23.98

[a]*Absolute abundance (AA) and confidence intervals (CI) expressed in tortoises per hectare.*
[b]*Value outside the calibration range.*

Table 3. Abundance classes of *Testudo graeca* populations in southeastern Spain and equivalences among relative and absolute abundance indexes obtained from interviews with shepherds and linear transects.

Abundance class[a]		*Interviews*[b]			*Transects*[c]	
main class	*subclass*	*logTY10*	*TY10*	*TD*	*AA*	*RA*
		0	1	1	0.03[d]	–
Very low		0.250	1.78	1	0.04[d]	–
		0.500	3.16	1	0.07[d]	–
Low		1.000	10	1	0.17[d]	–
		1.500	31.6	1	0.42	0.02
	1	1.665	46.2	1	0.57	0.03
		1.830	67.6	1.15	0.77	0.05
Medium	2	2.000	100	1.46	1.05	0.07
		2.170	148	1.93	1.44	0.09
	3	2.335	216	2.58	1.96	0.13
		2.500	316	3.54	2.66	0.18
	1	2.665	462	4.95	3.62	0.23
		2.830	676	7.01	4.91	0.30
High	2	3.000	1000	10.13	6.73	0.40
		3.170	1479	14.74	9.22	0.53
	3	3.335	2163	21.32	12.52	0.67

[a]*For each abundance class and subclass, the minimum, mean, and maximum values for different abundance indexes obtained from interviews and linear transects are given.*
[b]*Abundance indexes from interviews with shepherds: TY10, number of tortoises seen by the shepherd in 1 year on average multiplied by 10; TD, maximum number of tortoises seen by a shepherd in 1 day.*
[c]*Abundance indexes from linear transects: AA, absolute abundance (tortoises/ha); RA, relative abundance (tortoises encountered per person and per hour); -, not estimable with our field-sampling efforts.*
[d]*Values outside the calibration range.*

Relationships between LEK and Standard Scientific Protocol Results

The probability of detecting species with linear-transect sampling was around zero in localities with logTY10

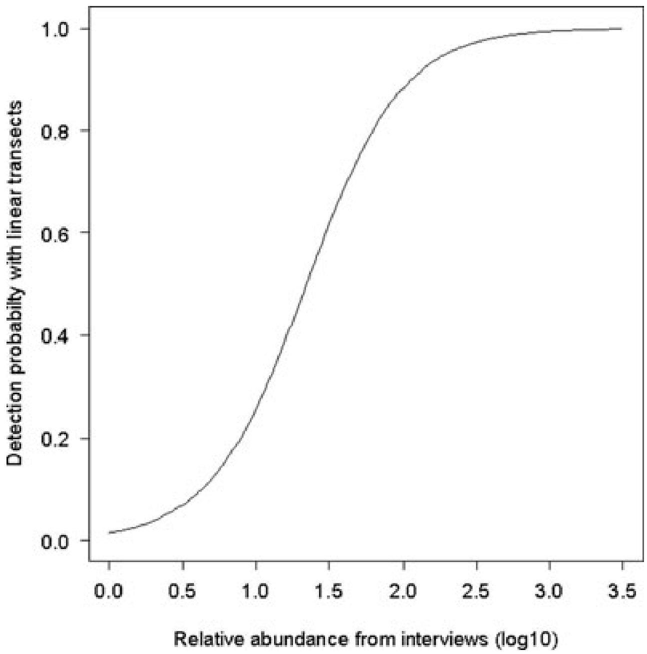

Figure 3. Relationship between the detection probability of tortoises in one locality determined with linear-transect sampling and the abundance obtained from interviews with shepherds.

<0.5 (i.e., <1 tortoise seen in 3 years) $D^2 = 60\%$; Fig. 3. Above this value, the probability of detecting tortoises with linear-transect sampling increased, and it was close to 1 when logTY10 = 2.5 (i.e., 31 tortoises seen a year and a maximum of 3 tortoises seen in 1 day).

In localities where at least one tortoise was detected, the relative abundance determined from interviews and the absolute abundance determined with distance sampling were highly correlated ($R^2 = 90\%$; Fig. 1). The width of the confidence intervals for the estimates of logAA ranged from 0.31 to 0.76 units of logAA, depending on whether the mean of TY10 was in the center or near the extreme of the abundance range (examples in Table 1). On the other hand, the distance between 2 estimates of the mean value of TY10 required to yield nonoverlapped estimates of logAA ranged between 0.4 and 0.72 units of logTY10 (examples in Table 2).

The width of the predictive bands was approximately 0.8 units of logAA (Fig. 1 & Table 1) for one locality with one estimate of TY10. The distance between 2 TY10 estimates required to yield nonoverlapped estimates was 1.2 log units of logTY10.

By linking all the abundance indexes, we obtained a classification system for the abundance of spur-thighed tortoise populations in southeastern Spain (Table 3). The 4 main abundance classes corresponded to the log classes of TY10: very low (0–0.5), low (0.5–1.5), medium (1.5–2.5), and high (>2.5). Tortoises were found only by means of linear transects in medium and high abundance classes, that is, in localities above 0.42 tortoise per hectare and with more than 0.02 tortoises observed per observer and hour (one encounter of tortoise per 50 hours of searching per person).

Cost Analysis

All interviews were completed in 51 days by one interviewer. Thus, information on abundance was gathered for 11.6 cells per day and interviewer. We estimated a journey of 106.6 km was made per interview, resulting in 18.9 km and 0.086 people days per cell to gather information on abundance. For linear-distance sampling, we estimated a journey of 49.9 km for each location. For 3 visits per population in 1 year with 3 people per transect, the total cost per cell was 9 people days with journeys of 149.7 km.

Discussion

Interviews with shepherds were a source of high-quality and low-cost information about both the distribution and abundance of the spur-thighed tortoise. In 51 days we collected reliable information about the current abundance of the species in roughly 40% of the study area (approximately 1500 km^2). To our knowledge the distribution and abundance data we gathered through interviews with shepherds constitutes the largest data set about local abundance of a terrestrial tortoise on a regional scale. The applications of these large, but low-cost, data sets are obvious. Analogous extensive data acquired through interviews has been used previously to determine the factors shaping the distribution of *T. graeca*, to build predictive distribution models, and to assess historic habitat loss (Anadón et al. 2006, 2007).

Reliability and Cost of LEK Data

The potential of local knowledge to provide reliable information about the properties of particular biological systems has not yet been thoroughly evaluated (but see Poizat & Baran 1997; Lyver & Gunn 2004; Gilchrist et al. 2005; Lozano-Montes et al. 2008; Jones et al. 2008). Specifically, and to the best of our knowledge, no works exist that quantify the uncertainty of predictions of abundance as our work does.

For practical reasons it would be difficult to exceed our sampling effort in an extensive monitoring program of this species. Despite the high sampling effort, only those localities with high densities (>5 individuals per hectare) had acceptable CV values of estimates of abundance (19–35%) (Swann et al. 2002; Freilich et al. 2005). Furthermore, tortoises were not considered present in those localities where shepherds encountered <2 or 3 tortoises a year (approximately <0.5 individuals hectare). In all these areas of medium and low density, which may comprise over 75% of the species' range (authors, unpublished data), reliable study and monitoring of tortoise populations through the use of linear transects is not affordable.

In localities where tortoises were encountered, the relative quantitative abundance index obtained from LEK correlated very highly with the absolute abundance obtained with distance sampling. This close relationship between these 2 measures allowed highly accurate predictions of mean absolute abundance for groups of localities. It was also possible to detect differences between groups of locations (or between different periods for the same group) when the mean absolute abundance of one group was twice that of the other (Table 2). For a species such as *T. graeca*, whose abundance range spans several orders of magnitude, this discriminatory ability is remarkable. From a conservation perspective, LEK can be used to detect population trends between, for example, groups of locations that share the same environmental conditions or threats. On the other hand, the accuracy of predictions of absolute abundance and population trends based on local knowledge in just one locality was low, as the wider prediction confidence intervals showed (Fig. 1 & Table 1). Nevertheless, this result is notable because it means LEK can be used reliably to assign one location to a main abundance class by simply using a low-cost sampling method, such as one interview.

Results of the cost analysis showed that information obtained by exploring LEK was 100 times less expensive than that obtained with standard field-sampling protocols. These differences were not only of an economic nature but were also related to time. The 595 cells that provided information about abundance were studied in 51 days, the same time needed to sample the 17 cells with distance sampling methods (17 × 3 days). This low cost allows for extensive sampling on large scales, which would otherwise be impossible to carry out.

Complementarity of LEK and Standard Sampling Methodologies

It has been pointed out that LEK and more standard scientific methods yield complementary approximations (Moller et al. 2004). Table 3 constitutes a good example of this complementarity. On one hand, local knowledge provided reliable information about the presence and relative abundance of tortoises over a much larger range than standard field-sampling protocols, including for populations with very low densities. The abundance index obtained from LEK defined the main abundance classes of the species. On the other hand, transect sampling and distance analysis allowed us to obtain absolute abundance values and to calibrate the relative abundance obtained from LEK. The final result was a sampling and classification system that allowed us to estimate the absolute abundance values, even at very low densities (very useful but expensive information), starting from a low-cost index of relative abundance. This sampling scheme is thus similar to double-sampling methodologies (Thompson 2002).

Because LEK is based on experiences over lengthy time periods, LEK provides information on past situations (Ferguson et al. 1998; Moller et al. 2004). We explored only the information related to the last decade. Nevertheless, interviews provided information about the presence and abundance of species since the 1950s. This information could be used to diagnose declines of species in the last decades and to assess baseline values in relation to the distribution and abundance of species (Lozano-Montes et al. 2008). Nevertheless, because the interviewees' memories, and thus the accuracy of the information, are expected to decline with time (Bernard et al. 1984), the prediction errors we obtained may not be valid for the data on past decades, and further analysis may be needed to deal with this data in depth.

Applicability of LEK to Other Case Studies

Interviews with shepherds showed they have a truly remarkable ability to describe the abundance of *T. graeca*; however, this does not mean LEK will perform as well in other case studies. Reliability of the distribution data and abundance estimates obtained from LEK and the feasibility of obtaining this information depends on various factors. In our opinion, adjusting the spatial and temporal grain of the target processes being characterized is a key issue when exploring local knowledge. In our case, for example, our target process (i.e., the frequency of encounters of tortoises by local inhabitants) was characterized at a 1-km^2 resolution and with a temporal grain of 1 decade. Any interpretation of LEK data beyond these grain limits is likely to be flawed. Previous knowledge of the focal socioecological system is required to properly adjust the temporal and spatial scales of the target process.

Reliability of exploration of local knowledge also depends strongly on characteristics of the target taxa and the interviewee population. Two features are likely to determine reliability relative to the taxa: the taxa should be easily recognizable and its detection should not need any particular skills. *T. graeca* is an unmistakable animal with a strong cultural dimension in local communities of the study area (Perez et al. 2004). It is expected that in other case studies as the difficulty of identifying and detecting the target species increases, the sampling error also will increase, whereas the number of potential interviewees will decrease, which increases sampling cost. Regarding the interviewee population, traditional shepherds constitute an ideal group of informants about animal and plant distribution and abundance. Unfortunately, such an ideal group of "experts" may not be available in other socioecological contexts. It is nonetheless advisable to select subjects whose main "sampling" activity is easy to measure and standardize and who together form as homogeneous a group as possible. As we relax the selection criteria for interviewees, the potential number of interviewees increases, but it is likely that the sampling error will also increase. In addition, in some cases the interviewed population may not be honest. This may happen when people are reluctant to share their knowledge because the species has an economic or cinegetic value (Grant & Berkes 2007) or because they believe the information may be used against them (e.g., declaring protected areas and hampering the "development" of an area, J.D.A., unpublished data). The selection of an adequate group of "experts" and the proper use of sociological tools, such as semidirect or in-depth interviews (Huntington 1998, 2000) can partially overcome this issue (Jones et al. 2008).

Nevertheless, we believe our results should encourage consideration of LEK as one more of the possible standard tools for extensively sampling the abundance of species. Furthermore, our results also highlight the ability of LEK to serve as a reliable tool for monitoring mid- to long-term population trends. Local ecological knowledge can be particularly useful when population densities are low and traditional sampling methods are expensive or difficult to implement, provided there are higher-density populations elsewhere that can serve to validate the LEK.

Acknowledgments

We thank the shepherds whose knowledge constitutes the basis of this work. We thank A. Pedreño for assistance during the design of the interview, J. Morales for guidance in the calibration analysis, G. López for introducing the authors to distance-sampling analysis, and all the people who participated in the linear samplings. J. Calabrese kindly reviewed the English text. An anonymous referee made valuable comments on an early draft of this work. This project was partially funded by the Spanish Council of Science and Technology (project CGL2004-01335), ACUSUR, and the Regional Government of the Region of Murcia. We also acknowledge the support of the Junta of Andalucía.

Literature Cited

Anadón, J. D., A. Giménez, M. Martínez, J. Martínez, I. Pérez, and M. A. Esteve. 2006. Factors determining the distribution of the spur-thighed tortoise *Testudo graeca* in southeast Spain: a hierarchical approach. Ecography **29**:339–346.

Anadón, J. D., A. Giménez, M. Martínez, M. A. Esteve, and J. A. Palazón. 2007. Assessing changes in habitat quality due to land use changes in *Testudo graeca* using hierarchical predictive habitat models. Diversity and Distributions **13**:324–331.

Anderson, D. R., K. P. Burnham, B. C. Lubow, L. E. N. Thomas, P. S. Corn, P. A. Medica, and R. A. Marlow. 2001. Field trials of line transect methods applied to estimation of desert tortoise abundance. Journal of Wildlife Management **65**:583–597.

Averill-Murray, R. C., and A. Averill-Murray. 2005. Regional-scale estimation of density and habitat use of the desert tortoise (*Gopherus agassizii*) in Arizona. Journal of Herpetology **39**:65–72.

Berkes, F., J. Colding, and C. Folke. 2000. Rediscovery of traditional ecological knowledge as adaptive management. Ecological Applications **10**:1251–1262.

Beshkov, V. A. 1993. On the distribution, relative abundance and protection of tortoises in Bulgaria. Chelonian Conservation Biology **1**:53–62.

Bernard, H. R., P. Killworth, D. Kronenfeld, and L. Sailer. 1984. The problem of informant accuracy: the validity of retrospective data. Annual Review of Anthropology **13**:495–517.

Buckland, S. T., D. R. Anderson, K. P. Burnham, J. L. Laake, D. L. Borchers, and L. Thomas. 2001. Introduction to distance sampling: estimating abundance of biological populations. Oxford University Press, Oxford, United Kingdom.

Cablk, M. E., and J. S. Heaton. 2006. Accuracy and reliability of dogs in surveying for desert tortoise (*Gopherus agassizii*). Ecological Applications **16**:1926–1935.

Chalmers, N., and C. Fabricius. 2007. Expert and generalist local knowledge about land-cover change on South Africa's Wild Coast: can local ecological knowledge add value to science? Ecology and Society **12**:10.

Davis, A., and J. R. Wagner. 2003. Who knows? On the importance of identifying "experts" when researching local ecological knowledge. Human Ecology **31**:463–489.

Draper, N. R., and H. Smith. 1998. Applied regression analysis. Wiley series in probability and statistics. John Wiley & Sons, New York.

Ferguson, M. A. D., R. G. Williamson, and F. Messier. 1998. Inuit knowledge of long-term changes in a population of arctic tundra Caribou. Arctic **51**:201–219.

Folke, C. 2004. Traditional knowledge in social–ecological systems. Ecology and Society **9**:7.

Freilich, J. E., K. P. Burnham, C. M. Collins, and C. A. Garry. 2000. Factors affecting population assessments of desert tortoises. Conservation Biology **14**:1479–1489.

Freilich, J. E., R. J. Camp, J. J. Duda, and A. E. Karl. 2005. Problems with sampling desert tortoises: a simulation analysis based on field data. Journal of Wildlife Management **69**:45–56.

Gadgil, M., F. Berkes, and C. Folke. 1993. Indigenous knowledge for biodiversity conservation. Ambio **22**:151–156.

Gilchrist, G., M. Mallory, and F. Merkel. 2005. Can local ecological knowledge contribute to wildlife management? Case studies of migratory birds. Ecology and Society **10**:20.

Grant, S., and F. Berkes. 2007. Fisher knowledge as an expert system: a case from the longline fishery of Grenada, the eastern Caribbean. Fisheries Research **84**:162–170.

Huntington, H. P. 1998. Observations on the utility of semi directive interviewing for documenting traditional ecological knowledge. Arctic **51**:237–242.

Huntington, H. P. 2000. Using traditional ecological knowledge in science: methods and applications. Ecological Applications **10**:1270–1274.

Jones, P. G., M. M. Andriamarovololona, N. Hockley, J. M. Gibbons, and E. J. Milner-Gulland. 2008. Testing the use of interviews as a tool for monitoring trends in the harvesting of wild species. Journal of Applied Ecology **45**:1205–1212.

Lambert, M. R. K. 1983. Some factors influencing the Moroccan distribution of the western Mediterranean spur-thighed tortoise, *Testudo graeca graeca* L., and those precluding its survival in NW Europe. Zoological Journal of the Linnean Society **79**:149–179.

Leedy, D. L. 1949. Ohio pheasant nesting surveys based on farmer interviews. Journal of Wildlife Management **13**:274–286.

Lozano-Montes, H. M., T. J. Pitcher, and N. Haggan. 2008. Shifting environmental and cognitive baselines in the upper Gulf of California. Frontiers in Ecology and Environment **6:**75–80.

Lyver, P. O'B., and A. Gunn. 2004. Calibration of hunters' impressions with female caribou body condition indices to predict probability of pregnancy. Arctic **57:**233–241.

McCullagh, P., and J. A. Nelder. 1987. Generalised linear modelling. Chapman and Hall, London.

McKenna, J., R. J. Quinn, D. J. Donnelly, and J. A. G. Cooper. 2008. Accurate mental maps as an aspect of local ecological knowledge (LEK): a case study from Lough Neagh, Northern Ireland. Ecology and Society **13:**13

Mallory, M. L., H. G. Gilchrist, A. J. Fontaine, and J. A. Akearok. 2003. Local ecological knowledge of Ivory Gull decline in arctic Canada. Arctic **56:**293–298.

Moller, H., F. Berkes, P. O. Lyver, and M. Kislalioglu. 2004. Combining science and traditional ecological knowledge: monitoring populations for co-management. Ecology and Society **9:**2.

Pérez, I., A. Giménez, J. D. Anadón, M. Martínez, and M. A. Esteve. 2002. Patrones de actividad estacional y diario de la tortuga mora *Testudo graeca* L. 1758 ssp. *graeca*. en el sureste de la península ibérica. Anales de Biología **24:**65–75.

Pérez, I., A. Giménez, J. A. Sanchez-Zapata, J. D. Anadón, M. Martínez, and M. A. Esteve. 2004. Noncommercial extraction of a threatened species: a cultural problem of *Testudo graeca graeca* in the Southeastern Spain. Biological Conservation **118:**175–181.

Poizat, G., and E. Baran. 1997. Fishermen's knowledge as background information in tropical fish ecology: a quantitative comparison with fish sampling results. Environmental Biology of Fishes **50:**435–449.

Smith, L. L., D. Reid, B. Robert, M. Joby, and S. Clément. 1999. Status and distribution of the angonoka tortoise (*Geochelone yniphora*) of western Madagascar. Biological Conservation **91:**23–33.

Swann, D. E., R. C. Averill-Murray, and C. R. Schwalbe. 2002. Distance sampling for Sonoran desert tortoises. Journal of Wildlife Management **66:**969–975.

Thomas, L., et al. 2004. Distance 4.1. Research Unit for Wildlife Population Assessment. University of St. Andrews, Scotland. Available from http://www.ruwpa.st-and.ac.uk/distance/ (accessed January 2007).

Thompson, S. K. 2002. Sampling. 2nd edition. John Wiley & Sons, New York.

Usher, P. J. 2000. Traditional ecological knowledge in environmental assessment and management. Arctic **53:**183–193.

Vaughan, N., E. Lucas, S. Harris, and P. L. White. 2003. Habitat associations of European hares *Lepus europaeus* in England and Wales: implications for farmland management. Journal of Applied Ecology **40:**163–175.

Zimmerer, K. S. 1991. The regional biogeography of native potato cultivars in highland Peru. Journal of Biogeography **18:**165–178.