African Journal of Ecology

Notes and records

Leopard population and home range estimates in north-central Namibia

Andrew B. Stein[1], Todd K. Fuller[1,*], Stephen DeStefano[2] and Laurie L. Marker[3]

[1]*Department of Environmental Conservation, University of Massachusetts, 160 Holdsworth Way, Amherst, MA 01003, U.S.A.,* [2]*USGS Massachusetts Cooperative Fish and Wildlife Research Unit, Amherst, MA, U.S.A. and* [3]*Cheetah Conservation Fund, Otjiwarongo, Namibia*

Introduction

Protected areas are commonly assumed to (and most do) harbour higher densities of wildlife than adjacent, human-modified landscapes (Woodroffe & Ginsberg, 1998; Melville & Bothma, 2006; Gaston *et al.*, 2008; Newmark, 2008; Kiner *et al.*, 2009). In north-central Namibia, farmers believed that leopard (*Panthera pardus*) densities were growing on farmland areas adjacent to Waterberg Plateau Park and that the Park was a source population for leopards venturing beyond park boundaries during the night to feed on the livestock in the farmlands (Stein, 2008). Leopard densities elsewhere have been correlated with ungulate abundance (Stander *et al.*, 1997; Marker & Dickman, 2005), but our camera surveys (Stein, Fuller & Marker, 2008) indicated that leopard prey was more abundant outside of versus inside the Park. Thus, we predicted that leopard density was higher outside of the Park and thus not a population 'sink' for leopards. To test this hypothesis, we estimated leopard density for both areas via capture–mark–recapture techniques using camera-trapping (e.g., Karanth & Nichols, 1998; Henschel & Ray, 2003; Silver *et al.*, 2004; Jackson *et al.*, 2006) combined with home range sizes estimated from telemetry data.

Materials and Methods

The 470-km^2 Waterberg Plateau Park (WPP; 20°17′S, 17°14′E) is a 200-m-high plateau covered by fountain plant and rocky outcrop communities, bush savannah, and mixed tree and shrub woodland (Schneider, 1998); annual rainfall averages 400–500 mm. Farmlands on the south-west border of WPP are managed for livestock and game (Stein, 2008) and covered with thick *Acacia* shrubland and woodland areas (Barnard, 1998; Schneider, 1998). In both the Park and the farmlands, leopards feed primarily on kudu (*Tragelaphus strepsiceros*), oryx (*Oryx gazelle*) and warthogs (*Phacochoerus aethiopicus*) (Zeiss, 1997; Stein, 2008). As evaluated through camera-trapping surveys, the relative abundance of these species was 3.9, 2.9 and 11.3 times greater, respectively, on farmlands (χ^2 tests; $P < 0.001$) versus within the Park (Stein, Fuller & Marker, 2008). Lions (*Panthera leo*), spotted hyaenas (*Crocuta crocuta*) and African wild dogs (*Lycaon pictus*) once occurred throughout the region but were essentially eliminated from both the Park and the farmlands by 1980s (Stein, 2008).

In the farmlands, two adult leopards (one male and one female) captured in cage traps (Univ. Mass., Amherst IACUC Protocol #24-02-09) were fitted with VHF collars; another captured adult female was fitted with a GPS collar. The VHF-collared animals were triangulated 1–3 times/week, and downloaded locations of the GPS-collared female averaged about 4/day (Stein, 2008). Leopard home range sizes were calculated (Animal Movements Extension, ArcView 3.2, Environmental Systems Research Institute Inc., Redlands, CA, U.S.A.) with discrete locations (minimum 24-hr interval; Stander *et al.*, 1997) using 50% and 95% kernel (Hooge, Eichenlaub & Soloman, 1999) and 95% minimum convex polygon methods (Mohr, 1947).

We monitored camera-trap stations (8 farmland and 11 WPP) consisting of two 35-mm film cameras (Deercam™; Nontypical Inc., Park Falls, WI, USA), each set at approximately 70 cm above the ground on opposite sides of a leopard trail or road, every 2–3 days during 2, 52-day sessions (June–Jul, Sep–Oct 2006; Stein, Fuller & Marker, 2008). Each station was placed about 3.6 km apart, the radius of 40-km^2 circle, and the size of the smallest leopard home range we documented (see below; Karanth & Nichols, 2002). We coded photographs of individual leopards (Henschel & Ray, 2003), created capture histories for each day (one or more photographs obtained from a trap in a

**Correspondence:* E-mail: tkfuller@eco.umass.edu

24-h period from noon to noon was deemed a single 'photo event'; Karanth, 1995; Karanth & Nichols, 1998, 2002) and used Program CAPTURE (Rexstadt & Burnham, 1991) to estimate numbers from capture/recapture statistics. To calculate density, we assumed each trap covered 71 km^2 (a 4.76-km radius circle), the average home range size of the 3 (two females, one male) radio-marked leopards we monitored (Soisalo & Cavalcanti, 2006; Dillon & Kelly, 2008; Sharma *et al.*, 2010), and thus effective coverage of 364 km^2 in the farmlands and 395 km^2 in WPP, given that no radio-monitored leopards in the farmland ever climbed the escarpment into the park (Fig. 1), and no leopards previously monitored in the park ever descended the escarpment into the farmlands (Zeiss, 1997).

Results

The 95% MCP home range of the male leopard (108 km^2) encompassed the ranges of both females almost entirely and, accordingly, was approximately twice the size of a single female (40 and 66 km^2; Table 1, Fig. 2). All three ranges were elongated and relatively parallel to the Waterberg Plateau escarpment (Fig. 2), and none ventured over the escarpment and into the Park.

In total, 79 leopard photographs were taken: 63 in the farmlands and 16 in the Park. Photo rates were higher (χ^2 = 8.95, 1 d.f., P = 0.003) in the farmlands (6/100 trap-nights; 25 photo events/401 camera-trap-nights) than in the Park (2/100; 12/545). From these photographs, 14 individual adult/subadult leopards were individually identified (10 on the farms and 4 in the Park, see Table 2), with two unidentifiable individuals within the park. Five individuals in farmlands were recaptured on 15 occasions (2–6 recaptures per individual) versus 10 recaptures of three individuals in the Park (2–5 recaptures per individual).

Using the best-fitting model (heterogeneity – (M(h)) within program CAPTURE, we calculated that the leopard

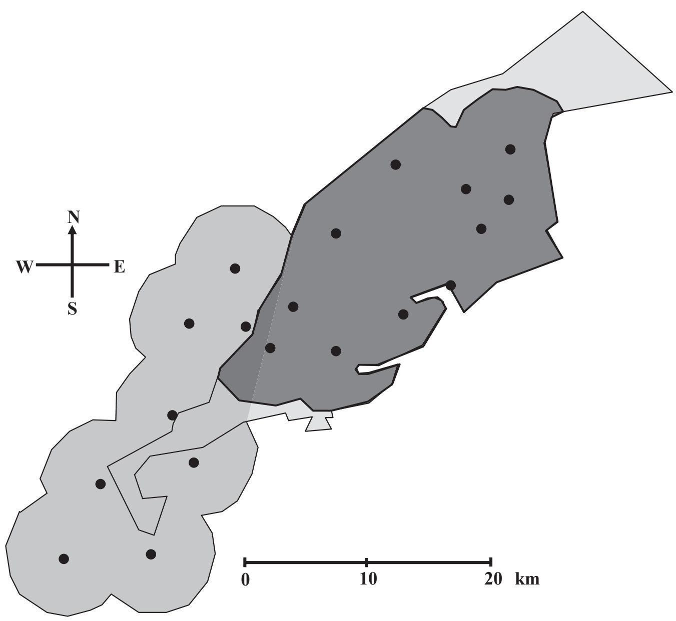

Fig 1 The locations of camera stations (black dots) within, and on farmlands surrounding, the Waterberg Plateau Park, Namibia (light gray polygon). The medium and darker gray areas around the points are the effective sampling area on the farmlands and within the Park, respectively, used to calculate leopard density

Table 1 Home range estimates (km^2) for VHF- or GPS-collared leopard monitored on commercial farmlands in north-central Namibia between August 2004 and October 2006 using 95% minimum convex polygon (MCP), 95% and 50% fixed kernel methods

Study animal	Sex	Collar type	No. of locations	95% MCP	95% Kernel	50% Kernel
PPA54	M	VHF	88	108	109	12
PPA51	F	VHF	115	66	46	7
PPA56	F	GPS	116	40	53	14

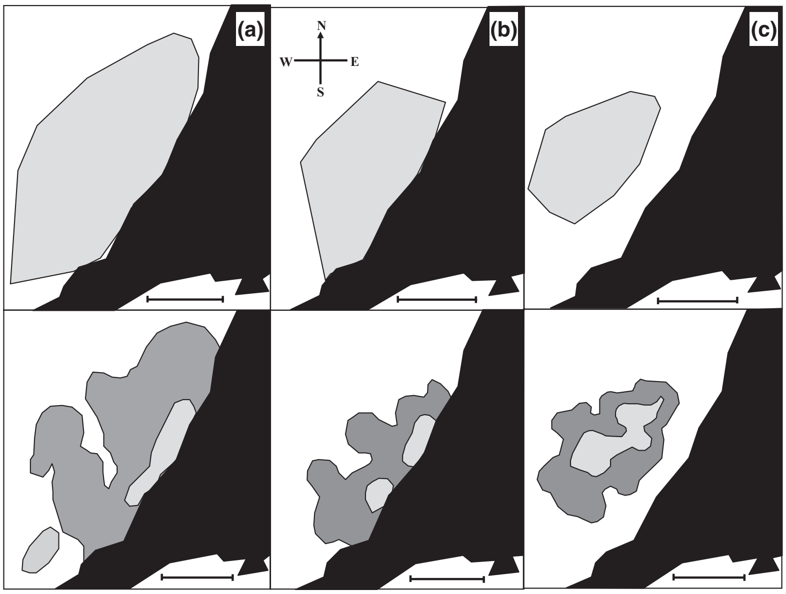

Fig 2 Minimum convex polygon (top, gray), and 95% (bottom, gray) and 50% (bottom, light gray) kernel, home range maps for a male leopard (PPA54 [A]), and two female leopards (PPA51 [B], and PPA%^[C]), radiomonitored from October 2004 through March 2006 on north-central Namibian farmland adjacent to the Waterberg Plateau Park (black). The scales indicate a distance of 5 km. As far as we could tell, none of the leopards climbed the escarpoment and moved into the Park

Table 2 Population estimates for leopards in the Waterberg Plateau Park and on adjacent farmland areas as determined by using the results of camera trapping data and the heterogeneity model (M(h)) within program CAPTURE (Rexstadt & Burnham, 1991)

Area	No. of individual		Estimated no. of leopards			Effective survey area size (km^2)	Density (no./100 km^2)
	Captures	Recaptures	*N*	SE	95%CI		
Park	4	10	4	0.7	3–6	395	1.0
Farmland	10	15	13	3.6	11–29	364	3.6

density (no./100 km^2) was significantly higher (Z-score = 2.4; $P = 0.02$) in farmland areas (3.6, 95%CI = 3.0–8.0) than within the Park (1.0, 0.8–1.5; Table 2). The ratio of photographed to nonphotographed radio-marked leopards in the farmlands (2/3; 0.67) was similar to the ratio of total leopards photographed in the farmlands to the calculated estimated total there (10/13; 0.77).

Discussion

Despite its protected status, it appears that the lower abundance of leopard prey species limits the number of leopards within the Park and does indeed explain the disparity between the two adjacent areas. The Park has sandy soils and most ground water seeps into underground springs that feed groundwater wells on the farms along the base of the escarpment; as a result, overall productivity is relatively lower in the Park (Schneider, 1998).

This disparity in leopard density is consistent with the general trend in felid densities of correlating with resource availability (cf. Stuart, Macdonald & Mills, 1985; Stander *et al.*, 1997; Larrucea *et al.*, 2007; Di Bitetti *et al.*, 2008). Our Park leopard density estimate is similar to estimates from arid areas (Bothma & Le Riche, 1984; Stander *et al.*, 1997), and our farmland density is in line with that from the Serengeti (Schaller, 1972). Areas with more prey (Hamilton, 1976; Norton & Lawson, 1985; Jenny, 1996) provide more suitable habitat and higher densities of leopards (Hayward, O'Brien & Kerley, 2007). The areas with the highest reported densities are protected areas with high densities of leopard prey (Le Roux & Skinner, 1989; Bailey, 1993; Hayward *et al.*, 2006).

Several studies evaluating estimate accuracy using camera-traps have been performed (c.f. Soisalo & Cavalcanti, 2006; Dillon & Kelly, 2008; Sharma *et al.*, 2010), and the potential for errors, especially with respect to estimating study area size, is clear (Dillon & Kelly, 2007; McCarthy *et al.*, 2008). In our study, the results match estimates of the regional leopard population density (Hanssen & Stander, 2004) and were likely improved by the incorporation of study area telemetry data.

Large carnivore management, in general, often lacks the ability to monitor changes in populations, and any technological insights into better assessing densities is worthwhile. Importantly, our results confirm the importance of prey abundance as a driving factor in potential predator abundance and highlight the need to critically review the role protected areas play in conservation. It seems likely that in many areas, wise management in areas outside of protected zones have high potential for conserving carnivores, given appropriate habitat information.

Acknowledgements

We thank the Namibian Ministry of Environment and Tourism, the WPP, E. Tjiteere, the Cheetah Conservation Fund, the Wildlife Conservation Society, the University of Massachusetts, Amherst, field assistants and reviewers.

References

Bailey, T.N. (1993) The African Leopard: Ecology and Behavior of a Solitary Felid. Columbia University Press, New York.

Barnard, P. (1998) Biological Diversity in Namibia: a Country-wide Study. Namibian National Biodiversity Task force, ABC Press, Cape Town.

Bothma, J.D. & Le Riche, E.A.N. (1984) Aspects of the ecology and the behaviour of the leopard *Panthera pardus* in the Kalahari Desert. *Koedoe* **27**(Suppl.), 259–279.

Di Bitetti, M.S., Paviolo, A., De Angelo, C.D. & Di Blanco, Y.E. (2008) Local and continental correlates of the abundance of a neotropical cat, the ocelot (*Leopardus pardalis*). *J. Trop. Ecol.* **24,** 189–200.

Dillon, A. & Kelly, M.J. (2007) Ocelot *Leopardus pardalis* in Belize: the impact of trap spacing and distance moved on density estimates. *Oryx* **41,** 469–477.

Dillon, A. & Kelly, M.J. (2008) Ocelot home range, overlap and density: comparing radio telemetry with camera trapping. *J. Zool.* **275,** 391–398.

Gaston, K.J., Jackson, S.E., Cantu-Salazar, L. & Cruz-Pinon, G. (2008) The ecological performance of protected areas. *Annu. Rev. Ecol., Evol. Syst.* **39,** 93–113.

Hamilton, P.H. (1976) The movements of leopards in Tsavo National Park, Kenya, as determined by radio-tracking. M.Sc. thesis, University of Nairobi.

Hanssen, L. & Stander, P.E. (2004) Namibia Large Carnivore Atlas. Predator Conservation Trust, Windhoek.

Hayward, M.W., O'Brien, J. & Kerley, G.I.H. (2007) Carrying capacity of large African predators: predictions and tests. *Biol. Conserv.* **139,** 219–229.

Hayward, M.W., Henschel, P., O'Brien, J., Hofmeyr, M., Balme, G. & Kerley, G.I.H. (2006) Prey preferences of the leopard (*Panthera pardus*). *J. Zool.* **270,** 298–313.

Henschel, P. & Ray, J. (2003) Leopards in African Rainforests: Survey and Monitoring Techniques. Wildlife Conservation Society, New York.

Hooge, P.N., Eichenlaub, W. & Soloman, E. (1999) The Animal Movement Program. USGS, Alaska Biological Science Center, Glacier Bay.

Jackson, R.M., Roe, J.D., Wangchuck, R. & Hunter, D.O. (2006) Estimating snow leopard population abundance using photography and capture-recapture techniques. *Wildl. Soc. Bull.* **34,** 772–781.

Jenny, D. (1996) Spatial organization of leopards Panthera pardus in Tai National Park, Ivory Coast: is rainforest habitat a 'tropical haven'?. *J. Zool.* **240,** 427–440.

Karanth, K.U. (1995) Estimating tiger *Panthera tigris* populations from camera-trap data using capture-recapture models. *Biol. Conserv.* **71,** 333–338.

Karanth, K.U. & Nichols, J.D. (1998) Estimation of tiger densities in India using photographic captures and recaptures. *Ecology* **79,** 2852–2862.

Karanth, K.U. & Nichols, J.D. (eds) (2002) Monitoring Tigers and Their Prey. Centre for Wildlife Studies, Bangalore.

Kiffner, C., Meyer, B., Muhlenberg, M. & Waltert, M. (2009) Plenty of prey, few predators: what limits lions *Panthera leo* in Katavi National Park, western Tanzania? *Oryx* **43,** 52–59.

Larrucea, E.S., Serra, G., Jaeger, M.M. & Barrett, R.H. (2007) Censusing bobcats using remote cameras. *West. N. Am. Nat.* **67,** 538–548.

Le Roux, P.G. & Skinner, J.D. (1989) A note on the ecology of the leopard (*Panthera pardus* Linnaeus) in the Londolozi game reserve, South Africa. *Afr. J. Ecol.* **27,** 167–171.

Marker, L.L. & Dickman, A.J. (2005) Factors affecting leopard (*Panthera pardus*) spatial ecology, with particular reference to Namibian leopards. *S. Afr. J. Wildl. Res.* **35,** 105–115.

McCarthy, K.P., Fuller, T.K., Ming, M., McCarthy, T.M., Waits, L. & Jumabaev, K. (2008) Assessing estimators of snow leopard abundance. *J. Wild. Manage.* **72,** 1826–1833.

Melville, H.I.A.S. & Bothma, J.D. (2006) Using spoor counts to analyse the effect of small stock farming in Namibia on caracal density in the neighboring Kgalagadi Transfrontier Park. *J. Arid Environ.* **64,** 436–447.

Mohr, C.O. (1947) Table of equivalent populations in North American small mammals. *Am. Midl. Nat.* **37,** 233–249.

Newmark, W.D. (2008) Isolation of African protected areas. *Front. Ecol. Environ.* **6,** 321–328.

Norton, P.M. & Lawson, A.B. (1985) Radiotracking of leopards and caracals in the Stellenbosch area, Cape Province. *S. Afr. J. Wildl. Res.* **15,** 17–24.

Rexstadt, E. & Burnham, K.P. (1991) User's Guide for Interactive Program CAPTURE. Abundance Estimation for Closed Animal Populations. Colorado State University, Fort Collins.

Schaller, G.B. (1972) The Serengeti Lion. Columbia University Press, New York.

Schneider, I. (1998) Waterberg Plateau Park Namibia: A Shell Guide. John Meinert Printing, Namibia.

Sharma, R.K., Jhala, Y., Qureshi, Q., Vattakaven, J., Gopal, R. & Nayak, K. (2010) Evaluating capture-recapture population and density estimation of tigers in a population with known parameters. *Anim. Conserv.* **13,** 94–103.

Silver, S.C., Ostro, L.E.T., Marsh, L.K., Maffei, L., Noss, A.J., Kelly, M.J., Wallace, R.B., Gomez, H. & Ayala, G. (2004) The use of camera traps for estimating jaguar *Panthera onca* abundance and density using capture/recapture analysis. *Oryx* **38,** 148–154.

Soisalo, M.K. & Cavalcanti, S.M.C. (2006) Estimating the density of a jaguar population in the Brazilian Pantanal using camera-traps and capture-recapture sampling in combination with GPS radio-telemetry. *Biol. Conserv.* **129,** 487–496.

Stander, P.E., Haden, P.J., Kaqece & Ghau (1997) The ecology of asociality in Namibian leopards. *J. Zool.* **242,** 343–364.

Stein, A.B. (2008) Ecology and conservation of the leopard (*Panthera pardus* Linnaeus 1758) in northcentral Namibia. Dissertation, University of Massachusetts, Amherst.

Stein, A.B., Fuller, T.K. & Marker, L.L. (2008) Opportunistic use of camera traps to assess habitat-specific mammal and bird diversity in northcentral Namibia. *Biodiv. Conserv.* **17,** 3579–3587.

Stuart, C.T., Macdonald, I.A.W. & Mills, M.G.L. (1985) History, current status and conservation of large mammalian predators in Cape Province, Republic of South Africa. *Biol. Conserv.* **31,** 7–19.

Woodroffe, R. & Ginsberg, J.R. (1998) Edge effects and the extinction of populations inside protected areas. *Science* **280,** 2126–2128.

Zeiss, B. (1997) Waterberg Leopard Project. Final Report to the Ministry of Environment and Tourism. Windhoek, Namibia.

(*Manuscript accepted 28 March 2011*)

doi: 10.1111/j.1365-2028.2011.01267.x