# Distance-based criteria to identify minimum number of brown bear females with cubs in Europe

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***Abstract:*** Counts of females with cubs-of-the-year (FWC) have been used as an index for monitoring brown bear (*Ursus arctos*) populations or estimating a minimum number of adult females in several small and medium-sized populations. Because discriminating among family groups is crucial to this procedure, we sought to improve criteria used to differentiate among FWC using spatial and temporal distances between sightings. We used telemetry data from 11 FWC from southern and central Europe and 15 FWC from Sweden to determine the likelihood that observations were of the same FWC based on the distance moved and elapsed time period. Euclidean distances traveled by each FWC were estimated daily. We then calculated straight-line distances traveled by each FWC using intervals of 1–180 days, or the maximum available. We obtained the maximum values (highest percentiles) of distances over time for each FWC. We considered 2 periods of bear activity: early spring, from first observations after denning until 30 June, and the remaining active season from 1 July until the onset of denning. Native FWC living in the boreal forest of Scandinavia moved farther than those living in the temperate forests of southern and central Europe. Differences among FWC in southern and central Europe may be related to habitat characteristics and to the origin (native or released) of the bears we studied. For example, based on the upper 95% prediction interval of the curve fitted of the 80 percentile in the early spring–June period, 2 observations 30 days apart are unlikely to be of the same individual if >13 km apart for FWC in the boreal forest, >15 km and >7 km, respectively, for released and native FWC in southern and central Europe. Our findings may be useful for biologists and managers to help differentiate FWC and thereby estimate the minimum number of family groups present, particularly in areas with low densities of FWC.

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Counting animals is a common activity of wildlife managers but it is particularly difficult to count carnivores, because they tend to occur at low densities and often are elusive (Linnell et al. 1998). A few researchers have conducted complete censuses of brown bear (*Ursus arctos*) populations (e.g., Miller et al. 1997), whereas others focused on developing indices of abundance (Kendall et al. 1992, Clevenger and Purroy 1996). In recent years, DNA-based censuses of brown bear populations have been tested extensively (Bellemain et al. 2005, Mowat et al. 2005). Tellería (1986) suggested that population indices should concentrate on segments of populations that can be identified most reliably. For brown bears, females with cubs-of-the-year (hereafter, FWC) constitute the most easily identifiable population segment (Knight et al. 1995, Palomero et al. 1997). Females are accompanied by cubs for a long time, are more active during daylight hours (Knight et al. 1995), and have smaller home ranges (Blanchard and Knight 1991, Dahle and Swenson 2003a), and less home-range overlap compared with other age and sex classes (Mace and Waller 1997, Støen et al. 2005). In addition, litter sizes are limited (most often 1–3) and mothers, cubs, or both can have recognizable marks (Campo et al. 1984, Knight et al. 1995) that make them easier to identify than other individuals (Naves et al. 1999, Schwartz et al. 2003, Bellemain et al. 2007). Counts of FWC have been used to monitor brown bear populations and estimate the minimum number of adult females in relatively small populations in Europe (Campo et al. 1984, Palomero et al. 1997) and North America (Knight and Eberhardt 1984, 1985; Knight et al. 1995; Keating et al. 2002; Schwartz et al. 2002).

The utility of FWC counts is based on the assumption that trends in this important segment of the population are correlated with trends in the population (i.e., growth rate, $\lambda$) as a whole. This may be true only if the raw, and probably biased, counts of FWC are in some way corrected (Keating et al. 2002) and if demographic parameters (e.g., age distribution of the population, age of first reproduction, reproductive intervals) are reasonably stable during the period of interest (Eberhardt and Knight 1996, Boyce et al. 2001). Annual counts of FWC can be useful to monitor bear populations (Mattson 1997, Linnell et al. 1998, Wiegand et al. 1998) by providing information regarding minimum population size, population trends, and reproductive success (Knight and Eberhardt 1985, Harris 1986, Servheen 1989, Palomero et al. 1997). In addition, the technique is relatively inexpensive and unobtrusive. However, several problems have been reported, including differences in sighting capability, sampling effort, and reporting rate of sighted FWC (Boyce 1995, Mattson 1997, Solberg et al. 2006), so more studies are necessary to define the reliability of the method (Craighead et al. 1995).

Criteria used to discriminate among different FWC often are based on the spatial and temporal distance among sightings and family group descriptions (number of cubs, size, color, and markings; Knight et al. 1995, Bellemain et al. 2007). Distance criteria have been used in USA (Knight et al. 1995), Spain (Campo et al. 1984, Palomero et al. 1997), and Scandinavia (Zakrisson 2001, Kristoffersen 2002). Information gathered from radiotracking FWC can improve the criteria based on distances between sightings, adding objectivity when distinguishing among family groups (Zakrisson 2001, Kristoffersen 2002).

The objective of our study was to improve the criteria to differentiate unique FWC using the distance in space and time among sightings. Specifically, given the number of days between observations, we determined the likelihood of a FWC moving a given distance. The use of this approach reduces the probability of erroneously classifying a FWC seen multiple times as >1 FWC (i.e., making a type I error).

## Methods

### *Radiotelemetry data*

We gathered data on FWC from 9 study areas in Europe, collected between 1981 and 2003 (Table 1). During the period in which females and cubs are

**Table 1. Mean number of locations per brown bear female with cubs-of-the-year (FWC), by period and country of origin in Europe, 1981–2003.**

| Group | FWC (*n*) | Number of locations by period: Early spring to 30 Jun mean (range) | Number of locations by period: Jul to denning mean (range) |
|---|---|---|---|
| Native bears | | | |
| Southern and central Europe[a] | 6 | 27.5 (27–28) | 70.4 (14–150) |
| Sweden[b] | 15 | 42.5 (20–54) | 58.8 (32–123) |
| Released bears | | | |
| Southern and central Europe[c] | 5 | 54.8 (33–82) | 60.4 (16–137) |

[a]One FWC from Croatia (Huber and Roth 1993), 1 from Greece (Mertzanis et al. 2005), 2 from Slovenia (Kaczensky et al. 2003), 1 from Romania (Mertens and Promberger 2001), 1 from Spain (Naves et al. 2001).
[b]Fifteen FWC from Sweden (Scandinavian Brown Bear Research Project; Zedrosser et al. 2006).
[c]Two FWC from Austria (Rauer et al. 2003), 1 from Italy (Mustoni et al. 2003), and 2 FWC from Pyrenees (France–Spain; Quenette et al. 2001).

together and active (i.e., excluding the denning season), we selected 1 location/day for each FWC, because our aim was to analyze straight-line distances on a daily basis. When >1 locations were available for a day, we chose the location that would result in the elapsed time between successive locations being closest to 24 hours. For every day with available locations, we calculated Euclidean distances between locations for each FWC using intervals from 1 to 180 days, or the maximum interval allowed by available data. We developed the distance data set for each FWC by calculating the distances between all pairs of daily locations within the sample period (e.g., distances traveled between day 1 and 2, day 1 and 3, day 2 and 3, day 2 and 4). Thus, the data set for each FWC contained distances corresponding to elapsed times among observations.

Most FWC reduce their movements during the mating season, possibly to avoid sexually selected infanticide (Kristoffersen 2002, Dahle and Swenson 2003b), a major cause of cub mortality in spring (Swenson et al. 1997), and are spatially segregated from other bears after emerging from dens (Miller et al. 1997, Haroldson et al. 2002). Thus, we considered 2 periods of bear activity: (1) early spring to the end of June, and (2) July to denning. The first period was from the first observation of each FWC (Mar–May) to June 30, the end of the mating season in Europe (Dahle and Swenson 2003c, Solberg et al. 2006, Fernández-Gil et al. 2006). The second period was from the beginning of July to den entry, including the season of hyperphagia. In portions of southern Europe, some bears may not den during some winters (Huber and Roth 1997), including some FWC (Naves et al. 2001). In those instances, we also used winter locations up to February. In addition to biological reasons, we considered the 2 periods defined above because surveys may be carried out only during a specific period in some areas (Servheen 1994); therefore, we intended to provide a distance-based tool for each period.

### Groups of FWC

Because the habitat of small populations of bears in southern and central Europe has some common features (e.g., fragmented forest cover, mostly deciduous forest, anthropogenic influence), we pooled data from the 9 populations. In several populations, female bears had been released during the 1990s to augment existing populations. The Scandinavian Brown Bear Project offered information from a boreal forest to contrast possible geographical differences among areas, thus we also included data from Sweden in our analyses (Table 1). Therefore, we divided the sample into 3 groups: native FWC ($n = 6$) in temperate forests of southern and central Europe, native FWC ($n = 15$) in boreal forests of Sweden, and released FWC ($n = 5$) in temperate forests of southern and central Europe.

### Statistical analysis

After developing data sets of distances moved by FWC for each time lag, we calculated the 80, 90, and 95 percentiles of distances for each FWC and time lag. Any distance above these values was very unlikely to have been traveled by the same family group. Thus, it may constitute an objective criterion to differentiate FWC. To test whether the division of the data base according to periods, geographical origin, and released versus native status was statistically supported, we used generalized linear models (GLM, McCullagh and Nelder 1983, Crawley 1993) to examine the explanatory ability of period and the 3 groups of FWC (explanatory variables) on the 80, 90, and 95 percentiles of the maximum distance traveled by FWC (dependent variable). In GLMs, we used the Type I error of PROC GENMOD (SAS Institute, Inc. 2000), which does not use iterative checking of explanatory power of all variables included in the model, but includes them in the given order. This procedure is frequently used when correcting for some factors. Because distance traveled depends on elapsed time between observations, we first included the variable 'time', followed by 'period,' and 'FWC group'. We also tested whether these relationships differed among individual bears (i.e., included individual bear as a variable along with elapsed time, period, and group). Statistical analyses were performed with SAS (2000).

In addition, we used nonlinear regression with all FWC groups and the 2 periods to describe relationships between travel distance and time. We used a nonlinear approach, because distances traveled between 2 observations are expected to be larger when time lags are longer, but a threshold is also expected, because movements ultimately are constrained by the home range (Zakrisson 2001, Kristoffersen 2002).

Using the predictive equation from statistical models, we determined the likelihood that an observed FWC had moved a particular distance during a given time. We applied Table Curve (Systat Software, Inc. San José CA, USA) to fit predictive curves to 80, 90, and 95 percentiles of distance traveled as a function of time for every FWC group and period. Among the potential curves generated for each period and group, we selected the curve with the largest $R^2$. Depending on the length of each period and available data (there were some gaps in data sets), the fitted curves had different lengths. We extended curves to the point (i.e., time-lag) where the amount of data did not decrease compared to shorter time lags between observations (e.g., for the early spring–end of Jun period of around 90 days, we only extended curves for a maximum of 55 days because we still had 35 observations to calculate percentiles for this time lag).

## Results

When accounting for elapsed time between observations ($\chi^2 = 37.1$, $P < 0.001$), distance traveled by each FWC depended on period of the year ($\chi^2 = 196.9$, $P < 0.001$) and FWC group ($\chi^2 = 398.0$, $P < 0.001$). In addition, the variable individual FWC was also significant ($\chi^2 = 3{,}208.6$, $P < 0.001$).

The nonlinear regression equations for a given FWC group and period provided a statistically-based (e.g., 80%, 90%, 95%) method of discriminating between 2 observations belonging to the same FWC and 2 observations belonging to distinct FWC (Table 2, Fig. 1, 2). In some instances, the 95 percentile was not obtainable because of small sample size. Figs. 1 and 2 show the 80 percentile regression equations fitted for every FWC group and period, as well as its upper 95 prediction interval. This is the most conservative approach to differentiate FWC, because most individual distances traveled by the females included in a given group and period are below that upper threshold. For example, 96.2% of the observations of native FWC in the boreal forest during the early spring–end of June occurred below the fitted curve, with individual FWC ranging from 80.4% (more mobile FWC) to 100% (less mobile FWC). Likewise for July–onset of denning, 97.5% of the observations were below the 95% prediction interval curve of the 80 percentile regression (individual range = 85.4–100%).

Based on the upper 95% prediction interval of the curve fitted to the 80% percentile in the early spring–June period (Fig. 1), 2 observations 30 days apart were unlikely to be of the same individual if >13 km apart for FWC in the boreal forest, >15 km (released FWC) and >7 km (native FWC) in southern and central Europe.

## Discussion

The distance between sightings of a FWC can help determine whether these sightings were of the same FWC. We found that distance traveled by FWC, corrected for elapsed time between observations, differed between periods (early spring–end of Jun, Jul–denning) and among FWC groups (native FWC in boreal forest; released and native FWC in southern and central Europe). Distances larger than the thresholds established by our fitted curves (Fig. 1, 2) are unlikely to be from the same FWC. Without additional criteria, distances below those thresholds may be of the same FWC, but the method does not allow differentiation of FWC. Therefore, distance-based criteria provided here should be used with additional criteria when possible, such as family group size and other characters, and may be most

**Table 2. Regression equations that describe distances moved by brown bear females with cubs (FWC) in Europe according to upper percentiles of distance traveled as a function of time, group of FWC, and period. y = distance traveled; x = number of days separating observations; a, b, and c are parameters from the models.**

| | | Group of FWC[a] | | |
|---|---|---|---|---|
| Period | Percentile | 1 | 2 | 3 |
| Early spring to the end of Jun | 80 | $y = a+bx^c$<br>a = 1.1<br>b = 476.6<br>c = 0.6<br>$R^2$: 50.6% | $y = a+b/x^{0.5}$<br>a = 10359.7<br>b = −8433.3<br>$R^2$: 26.5% | $y = a+bx^c$<br>a = −2019.5<br>b = 4965.5<br>c = 0.2<br>$R^2$: 15.9% |
| | 90 | $y = a+bx^c$<br>a = −243.6<br>b = 1257.1<br>c = 0.5<br>$R^2$: 69.5% | $y = a+bx^c$<br>a = 11701.7<br>b = −7629.6<br>c = −0.6<br>$R^2$: 20.7% | $y = a+bx^c$<br>a = −876.4<br>b = 5423.2<br>c = 0.2<br>$R^2$: 16.6% |
| | 95 | Insufficient data | $y = a+b/x^{(0.5)}$<br>a = 13266.9<br>b = −8032.8<br>$R^2$: 19.8% | Insufficient data |
| Jul to denning | 80 | $y = a+bx^c$<br>a = −1040.9<br>b = 3903.4<br>c = 0.2<br>$R^2$: 4.8% | $y = a+bx^c$.<br>a = −326.7<br>b = 8135.5<br>c = 0.2<br>$R^2$: 32.7% | $y = a+bx^{(0.5)}$<br>a = −520.8<br>b = 3598.9<br>$R^2$: 21.1% |
| | 90 | $y = a+bx^c$<br>a = 1039.2<br>b = 3867.5<br>c = 0.2<br>$R^2$: 3.01% | $y = a+bx^c$<br>a = 17706.4<br>b = −10235.1<br>c = −0.5<br>$R^2$: 15.2% | $y = ax^b$<br>a = 11835.4<br>b = 0.3<br>$R^2$: 17% |
| | 95 | $y = ax^b$<br>a = 6942.4<br>b = 0.1<br>$R^2$: 3.3% | $y = a+b/x^{(0.5)}$<br>a = 19452.2<br>b = −9928.4<br>$R^2$: 13% | $y = a+b/x^{(0.5)}$<br>a = 30340<br>b = −26469<br>$R^2$: 12.1% |

[a]Groups of FWC: 1 = native bears from southern and central Europe, 2 = native bears from the boreal forest of Sweden, 3 = released bears in southern and central Europe.

useful when trying to distinguish groups with the same number of animals (2 cubs is the most common litter size; Schwartz et al. 2003).

The variability in travel distances among groups and periods was large. It is important to note that our equations were fitted to the upper 80, 90, and 95 percentiles, which constitute the upper part of distance distribution. Thus, the curves do not represent the central tendency of the data. The inherent high variability of extreme values, and the individual variation within FWC groups, explains the generally low $R^2$ values of the non-linear regressions (Table 2, Fig. 1, 2). Fitting curves as we have done estimates the maximum distances that FWC within the 3 groups and 2 periods may move in a given time lag, in the presence of individual variation. In fact, most of the females moved less than our models predict; that is, our curves represent a highly conservative criterion that would avoid error type I to a large and quantifiable degree. However, in some groups females occasionally moved large distances. Most of these cases were related to human disturbances that moved the bears away from their normal areas of use (Naves et al. 2001, Mertzanis et al. 2005). The lowest $R^2$ was found for the native FWC group in southern and central Europe after July (Fig. 2), probably because we extended the period for FWC that did not den. The upper 95% prediction interval of the 80 percentile fitted curve included 100% of the distances traveled by 5 of the 6 females of this group and period and 95.6% of the distance values for the remaining FWC. That is why we also included the 95 percentile fitted curve for that group and period (Fig. 2c), which is very conservative and more accurately described the distance traveled by most of the FWC; 99.9% of the observations occurred below the 95 percentile fitted curve, although this value was 69.4% for the most mobile female (which was often disturbed by human activity; Mertzanis et

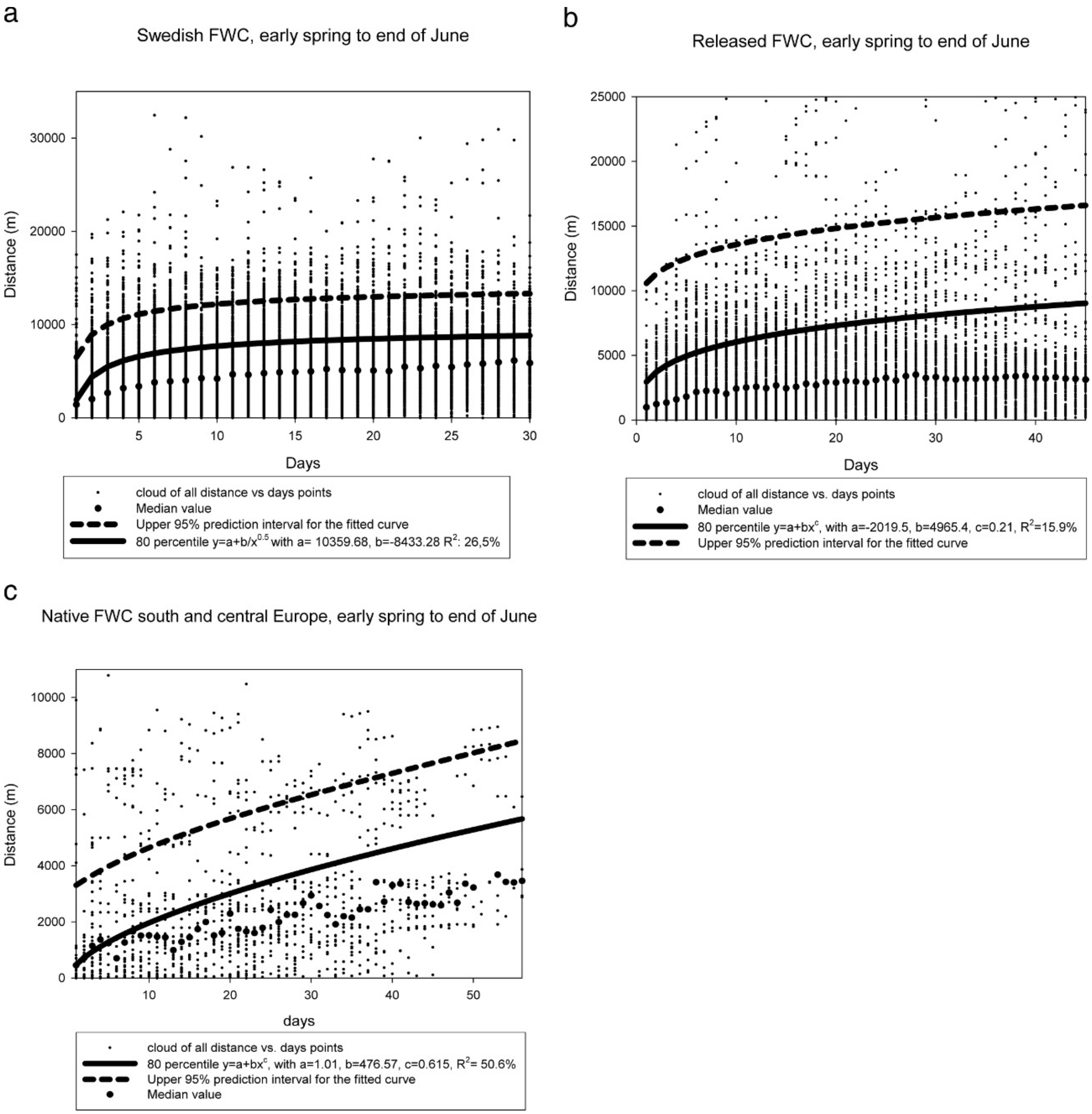


**Fig. 1. 80 percentile fitted curve and its upper 95% prediction interval, based on nonlinear regression of travel distance versus elapsed time between locations for 3 groups of female brown bears with cubs (FWC) in Europe, early spring–30 Jun, 1981–2003. Small points are distance traveled versus time lags, larger points are median values of observations for all females in each group. 1a: Native FWC in the boreal forest of Sweden. 1b: Released FWC in southern and central Europe. 1c: Native FWC in southern and central Europe.**

al. 2005), 100% for the 3 least mobile FWC, and >99% for the 2 remaining FWC.

For the purpose of estimating a minimum number of FWC, we suggest that the use of maximum distances is more reliable than the central tendency of the data. We have shown median distances traveled (Fig. 1, 2) to emphasize that the curves were fitted to maximum distances represented by an upper percentile and its upper 95% prediction interval as the most conservative option.

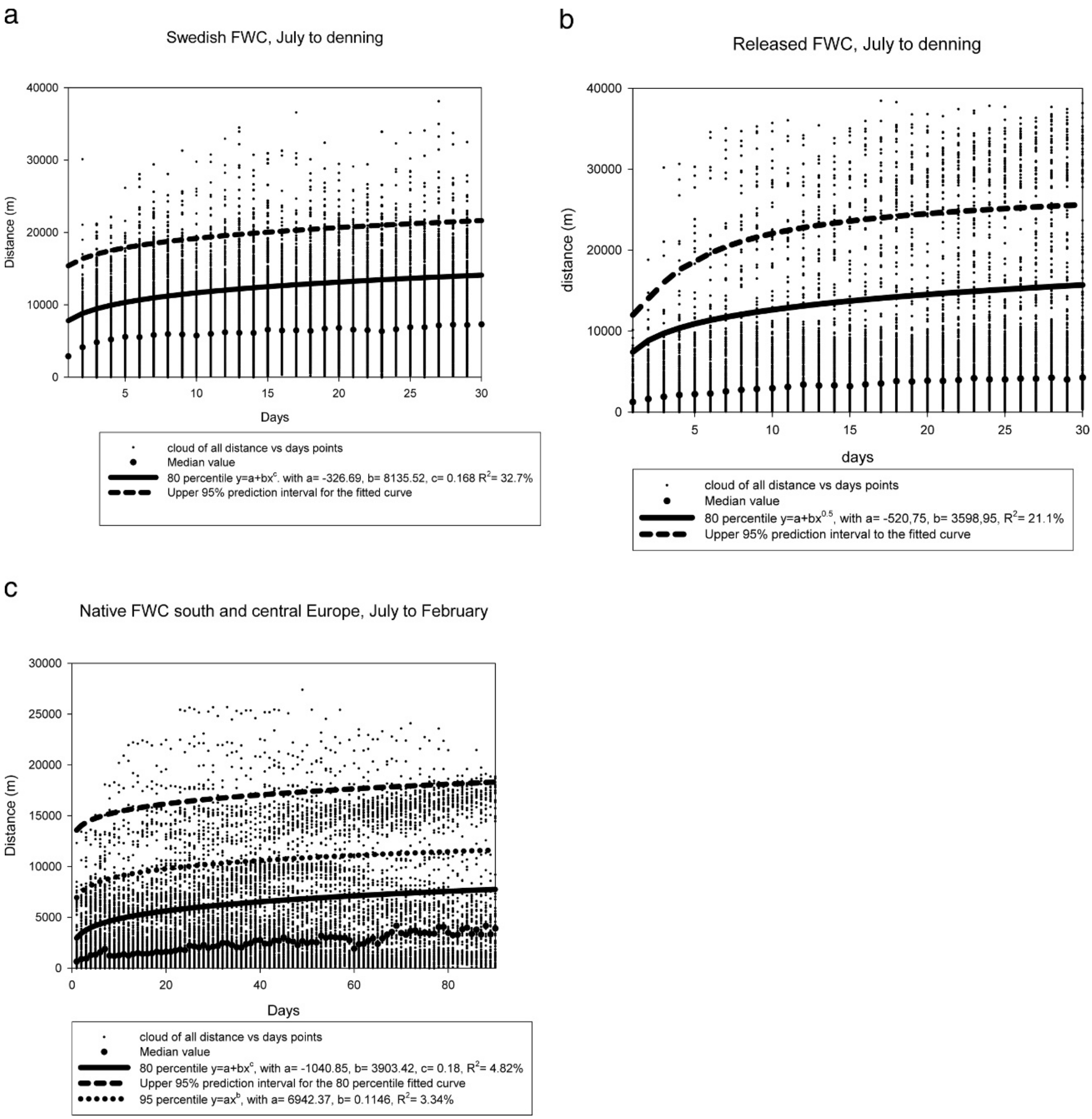


**Fig. 2. 80 percentile fitted curve and its upper 95% prediction interval, based on nonlinear regression of travel distance versus elapsed time between locations for 3 groups of female brown bears with cubs (FWC) in Europe, 1 Jul–onset of denning, 1981–2003. Small points are distance traveled versus time lags, larger points are median values of observations for all females in each group. 2a: Native FWC in the boreal forest of Sweden. 2b: Released FWC in southern and central Europe. 2c: Native FWC in southern and central Europe; 95 percentile fitted curve is shown, and the period includes Feb because some FWC did not den.**

Movement patterns differ among brown bear populations inhabiting different habitats in Europe (Dahle and Swenson 2003a). In general, released females in southern and central Europe and native FWC inhabiting boreal forests in Scandinavia moved farther than native FWC in southern and central Europe, regardless of the time of the year. Movement patterns of native bears were more consistent, whereas movements of some released females were highly variable, even when they have cubs-of-the-year, until they become acquainted with new areas. Actually, 87.7% of all distance values for these females were below the upper 95% prediction interval of the 80 percentile fitted curve, but for the most mobile female this percentage dropped to 50%. This variation among released bears requires further investigation and cautious application of this distance-based criterion, but this finding may have implications for reintroductions. Observations of native FWC in the boreal forest may be separated by distances close to the maximum even when separated by relatively short times (Fig. 1, 2). Distances traveled by native and released FWC in southern and central Europe did not reach an asymptote for either of the periods we examined. Therefore, the longer the time lags between observations, the greater the distances separating them.

We believe that our method to differentiate unique FWC improves former approaches by statistically relating the distance separating 2 observations of FWC to the lag between them. For example, in Yellowstone this lag was not accounted for by Blanchard and Knight (1991). They created a mobility index using standard diameters of annual home ranges of 31 FWC, using twice the mean value as a criterion to determine if FWC were the same, while also including other sources of information (Knight et al. 1995).

## Management implications

The methodology we present provides additional, objective distance-based criteria to estimate the minimum number of FWC for brown bears in areas of Europe. Keating et al. (2002) suggested that the number of FWC should be at least as high as that estimated. Therefore, it is often advisable to use the most conservative predictive models to avoid assigning observations of the same FWC to different FWC. Both upper 95% prediction intervals, shown in all the curves, and 95% percentile fitted curves, shown for native FWC in southern and central Europe, are conservative approaches (Table 2).

Because our models are based on maximum distances traveled, FWC separated by short distances (those well below the fitted curves) are not clearly distinguishable, so our findings are probably more reliable in areas with low bear densities (Solberg et al. 2006). Thus, the application of our method will result in conservative estimates, because some observations of different FWC will be considered to be the same FWC. Although the percent of home-range overlap among FWC is the lowest compared to any other bear–bear overlap (Mace and Waller 1997), Støen et al. (2005) have reported high degrees of home-range overlap by related females. When the application of family group-based criteria is not definitive, distance-based procedures may be a useful, additional tool to differentiate and count minimum numbers of unique FWC.

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