A. Challenges for transboundary management of a European brown bear population. Supplemental file.

# Parameters used for the matrix modelling

## Litter sizes and survival rates of COYs

During 5 years (2007-2011) of regular observations from hunting towers at feeding sites hunting right owners in Croatia counted a total of 431 females with 371 COYs and 493 yearlings accompanying their mothers. The calculated average litter size in Croatia in springtime was 2.17±0.12 (mean ± 1 SE, n=30), and 2.19±0.06 (n=140) in autumn. Because of small numbers of observations in spring, and because there was no difference between spring and autumn values (W=2086.5, p=0.95) we pooled data from both seasons, with the overall litter size for Croatia being 2.18±0.05 (n=170). The average number of yearlings in Croatia accompanied by their mothers in spring was 1.90±0.05 (n=159) and in autumn 1.87±0.06 (n=102). This difference was not significant (W=8299, p=0.71) so we pooled the seasons to give an overall estimate of 1.89±0.04 (n=261) yearlings per reproductive female.

For 7 observational years (2004-2010) in Slovenia, 646 females were counted accompanied by 784 COYs and 346 yearlings. The average litter size in Slovenia in springtime was 1.84±0.07 (n=86), and 1.81±0.04 (n=345) in autumn. There was no seasonal difference (W=15046.5, p=0.82) and overall litter size was set for Slovenia at 1.82±0.03 (n=431). The average number of yearlings in spring was 1.59±0.07 (n=102) and in autumn 1.63±0.05 (n=113, W=5427, p=0.41). Accordingly, the overall number of yearlings following their mothers in both seasons was set at 1.61±0.04 (n=215). In Croatia, the average litter size of 2.18 was higher than 1.82 in Slovenia (W=46798, p<<0.0001). We calculated the same values for both countries pooled. One thousand and seventy seven (1077) females were counted, accompanying 1155 COYs and 839 yearlings. Seasonal differences were not significant so we ended up with overall values of 1.92±0.03 (n=601) for litter size and 1.76±0.03 (n=476) for yearlings.

Survival rates for cubs in their first year of life (COYs) for non-hunting mortality (sncoy) were calculated from the above brown bear observation datasets. To estimate survival rates of the COYs we used the formula:

$s\_{ncoy}=\frac{n\_{y}}{n\_{coy}}$ (Eq. A1)

where ny is the average number of observed yearlings with mother and ncoy is the average number of observed COYs accompanying females (i.e. average observed litter size). The range of survival rate values that were possible we insured with the “betaval” function with a given standard deviation of 0.03. The “betaval” function produces a beta-distributed random number where the value of the mean rate is between 0 and 1 [1].

Estimates of survival rates for yearlings (snf1, snm1), subadult (snf2\_4, snm2\_4) and adult (snf5\_19, snm5\_19) male and female bears were taken from estimates obtained from the Scandinavian population [2] with data from Sweden. These are the only quantitative estimates of bear vital rates available from a large sample in Europe.

As the oldest recorded removed animal from either Croatia or Slovenia was 19 years of age we set survival rates at 0 for both sexes at age of 20.

## Other reproductive parameters

To take into account sexually selected infanticide (SSI; [3,4,5,6]) we introduced a parameter called “whole litter loses” (WL). WL was included in the model as a proportion of survived litters, in a form of 1-WL. Within this parameter, we included all other causes of mortality of COYs that can lead to loss of the entire litters. Loss of the whole litters could not be quantified from observation sites because we could not tell if females without any accompanying COY had failed to give birth or had lost her cubs. We assumed a value of WL=0.25 for Croatia based on values from the literature for loss of whole litters for brown bears in Scandinavia (WL=0.26) [7] and in south-central Alaska (WL=0.28) [6]. Since hunting mortality of adult males due to trophy hunting in Croatia is higher compared to Slovenia and probably resulted in increased infanticide [3,4], we set WL=0.125 for Slovenia and combined value for Croatia and Slovenia was set as WL=0.21. These values were supported by data from telemetry study in Slovenia (Jerina, unpublished data).

Another parameter closely linked with SSI and whole litter loss is inter-litter (interbirth) interval (ILI). Steyaert et al. [8] described when the entire litter loss took place, 91% of the females will enter oestrus, mate and give birth the next year, which can shorten inter-litter interval for 50% (in a case of 2-year ILI) to 85% (in a case of 5 or 6-year ILI). Zedrosser et al. [9] described the effects of whole litter loss on the inter-litter interval in primiparous and multiparous females. To parameterize our models we took ILI=1.75, 1.97 and 1.82 for Croatia, Slovenia and Croatia and Slovenia combined, as a result of approximate proportions of 1:5 of primiparous and multiparous females in the population structure, and that whole litter loss occurred in different percentages in each country (WL=0.25, 0.125 and 0.21), respectively.

Steyaert et al. [10] included a literature overview of the age of first female reproduction (age of primiparity). The average values from Sweden, from 5.2 to 5.4 years, corresponded well with other studies, with some regional differences [9]. In addition, Støen et al. [11] found socially induced delayed primiparity in south-central Sweden and southeastern Norway. The mean age of primiparity was 4.3±0.5 years for dispersing females and 5.2±0.6 years for philopatric females. Krofel et al. [12] presented values of 3 or 4 as an age of first reproduction in Slovenia. Zedrosser et al. [13] reported early primiparity in two brown bear females of 3 years of age in central Austria, and Frković et al. [14] reported a first reproduction in a single radio-collared female at the age of 3 and one at the age of 4 years. Reljić et al. [15] reported a case of ovulation in the ovaries of one captive brown bear female at the age of 2 years and 4 months. Based on the above data we have chosen that for Croatian and Slovenian bears half of the females (0.50, with a very wide range from 0.25 to 0.75) at the year of 3 age can reproduce and all females from 4 years of age and above.

Fecundity was calculated according to the formula:

$F=l\_{s}/ILI/2$ (Eq. A2)

where ls was litter size, ILI was an inter-litter interval and 2 was a number of sexes (if we presume that sex ratio at birth is equal, 1:1). To deal with uncertainties in parameter estimates in this formula for calculating the litter size we used the “rnorm” function to produce random numbers with a mean of ls value and standard deviation of 0.05. For females 16 to 19 years of age, we decreased fecundity by 7.5% as described in Schwartz et al. [16] in order to account for senescence.

The initial population size for Croatia was taken as 1000 [17] while recognising that this estimate is not very precise. For Slovenia, we took a starting level of 558 bears which was the average value of reported population estimates ranging from 513 to 603 animals [18,19] based on a genetic capture-recapture estimate.

1000 iterations were used in all simulations.

**Table A1. Parameters used for the matrix modelling.** Survival rates are related to non-quota removals. Hunting mortality was included later in the matrix in a form of a vector.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Parameter** | **Sign/Label** | **Value** | **95% CI (low-upp)** | **Reference** |
| Survival rate COYs Croatia | sncoyc | 0.87 | 0.85-0.88 | Results of this study |
| Survival rate COYs Slovenia | sncoys | 0.88 | 0.85-0.92 | Results of this study |
| Survival rate COYs Cro+Slo | sncoycs | 0.873 | 0.86-0.89 | Results of this study |
| Survival rate female yearlings | snf1 | 0.82 | 0.75-0.88 | [2] |
| Survival rate female subadults | snf2\_4 | 0.94 | 0.90-0.96 | [2] |
| Survival rate female adults | snf5\_19 | 0.93 | 0.91-0.95 | [2] |
| Survival rate male yearlings | snm1 | 0.91 | 0.82-0.96 | [2] |
| Survival rate male subadults | snm2\_4 | 0.82 | 0.76-0.87 | [2] |
| Survival rate male adults | snm5\_19 | 0.89 | 0.85-0.92 | [2] |
| Survival rate at the age of 20 years | sn20 | 0 |  | Supplemental files |
| Litter size Croatia | lsc | 2.18 | 2.08-2.28 | Results of this study |
| Litter size Slovenia | lss | 1.82 | 1.76-1.88 | Results of this study |
| Litter size Cro+Slo | lscs | 1.92 | 1.87-1.98 | Results of this study |
| Whole litter loses | WL | 0.28, 0.26, 0.25, 0.27 |  | [6,7,20,21] |
| * Croatia
 |  | 0.25 | 0.18-0.30 | Supplemental files |
| * Slovenia
 |  | 0.125 | 0.07-0.18 | Supplemental files |
| * Cro+Slo
 |  | 0.21 | 0.14-0.26 | Supplemental files |
| Inter-litter interval | ILI | 1.58-1.78 |  | Data from the present study, method from [8,9] |
| * Croatia
* Slovenia
* Cro+Slo
 |  | 1.751.971.82 | 1.57-1.931.85-2.091.65-2.00 | Supplemental files |
| Age of first female reproduction |  | 3.75 | 3.50-4.00 | Supplemental files |
| Age of first male reproduction |  | 3.75 | 3.50-4.00 | Supplemental files |
| Initial female:male ratio |  | 59.5:40.5 |  | [18] |
| Max. reproductive female:male ratio |  | 6:1 |  | [10] |
| Fecundity over 16 years |  | 0.93xF | 0.90-0.96 | [16] |
| Population size Croatia | Nc | 1000 | 750-1250 | [17] |
| Population size Slovenia | Ns | 558 | 513-603 | [18,19] |
| Population size Cro+Slo | NCS | 1558 | 1378-1738 | Supplemental files |
| Number of simulations | sim | 1000 |  | Supplemental files |

# Survival analysis

Survivorship was estimated as cumulative survival rate at each age stage, which includes survival rates from all previous age classes [22]. The oldest animal detected was 19 years of age, so we assumed that no animals lived beyond 20. Survivorship for each age stage for joint genders for total removal data was computed using the Kaplan-Meier survival distribution [23] with the built-in “survfit” function. We applied two libraries, “splines” and “survival”.

To calculate common and constant survival rates for adult age classes for both genders together we used the catch-curve analysis described in [22]. Regression functions relate to the descending arm of the slope.

Because hunting mortality patterns are contrastingly different in both countries due to different hunting regulations (mostly adult males in Croatia and subadults of both sexes in Slovenia) and a large proportion of individuals occupy ranges that span the border we estimated survival just for combined data from both countries and not separately for each of the countries. Survival rates gained from these two methods were not used in the matrix model but instead, we used published survival rates from the Scandinavian brown bear population [2].

Survivorship (cumulative survival) for the entire joined Croatian and Slovenian reported removal dataset for both sexes pooled at the end of the 4th year of life was 0.36±0.03 (n=1128; Figure A1). The complete results for each step (age class) of the survival analysis with Kaplan-Meier survival distribution are presented in Table A2. The common survival rate (Figure A2) for the overall population, i.e. the pooled Slovenian and Croatian data for age classes from 2 to 9 years (descending arm of the slope) was 0.70+0.032 (multiple R-sq.=0.9074, n=1128).

 

A1)



A2)

**Figures A1 and A2.** **Results of the survival analysis of brown bears in Slovenia and Croatia** **with:** A1) Kaplan-Meier survival distribution, and A2) Catch Curve analysis.

**Table A2. Results of the survival analysis with Kaplan-Meier survival distribution for each step (age class).** Survivorship is cumulative survival that sums survival rates after each period t.

|  |  |
| --- | --- |
|  | **CROATIA+SLOVENIA** |
|  time | n.risk | n.event | survival | std.err |  lower 95% CI | upper 95% CI |
| 1 | 1128 | 120 | 0.893617 | 0.009180 | 0.875804 | 0.91179 |
| 2 | 1008 | 192 | 0.723404 | 0.013319 | 0.697766 | 0.74998 |
| 3 | 816 | 228 | 0.521277 | 0.014874 | 0.492925 | 0.55126 |
| 4 | 588 | 185 | 0.357270 | 0.014268 | 0.330371 | 0.38636 |
| 5 | 403 | 112 | 0.257979 | 0.013027 | 0.233669 | 0.28482 |
| 6 | 291 | 60 | 0.204787 | 0.012015 | 0.182541 | 0.22974 |
| 7 | 231 | 40 | 0.169326 | 0.011167 | 0.148795 | 0.19269 |
| 8 | 191 | 53 | 0.122340 | 0.009756 | 0.104638 | 0.14304 |
| 9 | 138 | 40 | 0.086879 | 0.008386 | 0.071904 | 0.10497 |
| 10 | 98 | 14 | 0.074468 | 0.007817 | 0.060621 | 0.09148 |
| 11 | 84 | 28 | 0.049645 | 0.006467 | 0.038458 | 0.06409 |
| 12 | 56 | 20 | 0.031915 | 0.005234 | 0.023142 | 0.04401 |
| 13 | 36 | 12 | 0.021277 | 0.004297 | 0.014322 | 0.03161 |
| 14 | 24 | 6 | 0.015957 | 0.003731 | 0.010091 | 0.02523 |
| 15 | 18 | 4 | 0.012411 | 0.003296 | 0.007375 | 0.02089 |
| 16 | 14 | 5 | 0.007979 | 0.002649 | 0.004162 | 0.01529 |
| 17 | 9 | 5 | 0.003546 | 0.001770 | 0.001333 | 0.00943 |
| 18 | 4 | 2 | 0.001773 | 0.001253 | 0.000444 | 0.00708 |
| 19 | 2 | 1 | 0.000887 | 0.000886 | 0.000125 | 0.00629 |
| 20 | 1 | 1 | 0.00000 | NaN | NA | NA |

# Sex and age structure of the modelled population

****

A3)

****

A4)

****

A5)

**Figures A3, A4 and A5.** **Modelled population size and structure for Slovenia and Croatia combined, and in isolation.** For each scenario, the figures show initial conditions and then after 5 years modelling period.

**Table A3. Sex and age structure of the modelled population.** Percentages (%) of each sex and age class in combined Croatian and Slovenian population after 5 years of 1000 simulation run.

|  |
| --- |
| **Croatia + Slovenia** |
| Age | Females | Males |
| 0 | 13,851 | 13,851 |
| 1 | 8,941 | 8,945 |
| 2 | 6,610 | 7,082 |
| 3 | 5,340 | 4,720 |
| 4 | 4,292 | 1,858 |
| 5 | 3,232 | 0,687 |
| 6 | 2,736 | 0,403 |
| 7 | 2,499 | 0,380 |
| 8 | 2,190 | 0,377 |
| 9 | 1,807 | 0,372 |
| 10 | 1,520 | 0,338 |
| 11 | 1,257 | 0,203 |
| 12 | 1,068 | 0,190 |
| 13 | 0,930 | 0,191 |
| 14 | 0,755 | 0,146 |
| 15 | 0,628 | 0,180 |
| 16 | 0,537 | 0,147 |
| 17 | 0,448 | 0,109 |
| 18 | 0,379 | 0,087 |
| 19 | 0,324 | 0,062 |
| 20 | 0,271 | 0,056 |
| Total | 59,615 | 40,384 |

# References

1. R Documentation. 2014. Available from: http://127.0.0.1:15429/library/popbio/html/betaval.html
2. Bischof R, Swenson JE, Yoccoz NG, Mysterud A, Gimenez O. The magnitude and selectivity of natural and multiple anthropogenic mortality causes in hunted brown bears. J Anim Ecol. 2009;78: 656–665.
3. Swenson JE, Sandegren F, Söderberg A, Bjärvall A, Franzén R, Wabakken P. Infanticide caused by hunting of male bears. Nature. 1997;386: 450-451.
4. Swenson JE, Sandegren F, Brunberg S, Segerstrom P. Factors associated with loss of brown bear cubs in Sweden. Ursus. 2001;12: 69-80.
5. McLellan BN. Sexually selected infanticide in grizzly bears: the effects of hunting on cub survival. Ursus. 2005;16(2): 141-156.
6. Miller SD, Sellers RA, Keay JA. Effects of hunting on brown bear cub survival and litter size in Alaska. Ursus. 2003;14(2): 130-152.
7. Gonzalez O, Zedrosser A, Pelletier F, Swenson JE, Festa-Bianchet M. Litter reductions reveal a trade-off between offspring size and number in brown bears. Behav Ecol Sociobiol. 2012;66: 1025–1032.
8. Steyaert SMJG, Swenson JE, Zedrosser A. Litter loss triggers estrus in a nonsocial seasonal breeder. Ecol Evol. 2014;4(3): 300–310.
9. Zedrosser A, Dahle B, Støen OG, Swenson JE. The effects of primiparity on reproductive performance in the brown bear. Oecologia. 2009;160: 847–854.
10. Steyaert SMJG, Endrestøl A, Hackländer K, Swenson JE, Zedrosser A. The mating system of the brown bear *Ursus arctos*. Mamm Rev. 2012;42(1): 12–34.
11. Støen OG, Zedrosser A, Wegge P, Swenson JE. Socially induced delayed primiparity in brown bears *Ursus arctos*. Behav Ecol Sociobiol. 2006;61: 1–8.
12. Krofel M, Jonozovič M, Jerina K. Demography and mortality patterns of removed brown bears in a heavily exploited population. Ursus. 2012;23: 91-103.
13. Zedrosser A, Rauer G, Kruckenhauser L. Early primiparity in brown bears. Acta Theriol. 2004;49(3): 427-432.
14. Frković A, Huber D, Kusak J. Brown bear litter sizes in Croatia. Ursus. 2001;12: 103-106.
15. Reljić S, Sergiel A, Beck A, Kužir S, Radišić B, Maslak R, et al. Incidence of ovulation in brown bears as indicator of range of reproductive age. In 21st International Conference on Bear Research and Management Book of Abstracts. New Delhi: Wildlife Trust of India; 2012. p. 218.
16. Schwartz CC, Keating KA, Reynolds HV III, Barnes GV Jr, Sellers AR, Swenson JE, et al. Reproductive maturation and senescence in the female brown bear. Ursus. 2003;14(2): 109–119.
17. Kocijan I, Huber D. Conservation genetics of brown bears in Croatia. Final report. Project: Gaining and Maintaining Public Acceptance of Brown Bear in Croatia. BBI-Matra/2006/020 through ALERTIS. 2008.
18. Skrbinšek T, Jelenčič M, Potočnik H, Trontelj P, Kos I. Analiza medvedov odvzetih iz narave in genetsko-molekularne raziskave populacije medveda v Sloveniji [The analysis of removed bears from the population and the genetic-molecular research of the brown bear population in Slovenia]. Ljubljana: Univerza v Ljubljani, Biotehniška fakulteta. 2008. (In Slovenian)
19. Anonymous. Strokovno mnenje za odstrel velikih zveri za obdobje 01.10.2015. – 30.09.2016. [Expert opinion for the culling of large carnivores for period 01.10.2015 – 30.09.2016]. Ljubljana: Zavod za gozdove Slovenije. 2015. (In Slovenian)
20. Hristienko H, Pastuck D, Rebizant KJ, Knudsen B, Connor ML. Using reproductive data to model American black bear cub orphaning in Manitoba due to spring harvest of females. Ursus. 2004;15(1): 23-34.
21. Yamanaka A, Yamauchi K, Tsujimoto T, Mizoguchi T, Oi T, Sawada S, et al. Estimating the success rate of ovulation and early litter loss rate in the Japanese black bear (*Ursus thibetanus japonicus*) by examining the ovaries and uteri. Jpn J Vet Res. 2001;59(1): 31-39.
22. Skalski JR, Ryding KE, Millspaugh JJ. Wildlife demography. Analysis of sex, age, and count data. Burlington, Massachusetts, USA: Elsevier Academic Press. 2005.
23. Crawley MJ. The R Book. Chichester, West Sussex, England: John Wiley & Sons Ltd. 2007.