IMPACT OF BEAR-VEHICLE COLLISIONS ON SLOVENIAN-CROATIAN BROWN BEAR POPULATION AND ITS EXPANSION INTO THE ALPS

Action A.4: Impact of bear-vehicle collisions on brown bear population, determination of black spots and preparation of action plan of mitigation measures

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SUMMARY

Nowadays humans are the main cause of brown bear mortality. Such anthropogenic mortality includes vehicle collisions on roads and railways. Besides causing important part of mortality, transport infrastructure also have indirect negative effects connected with reduced gene flow and reduced functional connectivity of the landscape. In this report we present analysis of vehicle-caused mortality in the Slovene-Croatian part of the Alpine-Dinaric-Pindos brown bear population and evaluation of importance of vehicle collisions on expansion of the bear population into the Alps.

For analysis of mortality we used data of 891 bears removed from population in Slovenia during 2004-2012 and 535 bears removed in Croatia during 2005-2010. We analysed sex and age structure of bears killed in vehicle collisions and temporal (inter-annual and seasonal) trends of this mortality. For Slovenia we also calculated sex- and age-specific vehicle-caused mortality according to the reconstructed structure of the entire population in the country and for the Alpine part we furthermore evaluated demographic self-sustainability of this part of the population and effects of vehicle collisions on it, using simplified age-non-structured model.

During 2005-2010 in total 181 bears were recorded killed in vehicle collisions in Slovenia and Croatia (on average 30 bears/year), which represents 17% of all recorded bear mortality and is, following legal hunting, the second most important cause of bear mortality in these two countries. Overall, 17.7% of vehicle collisions occurred on highways, 40.3% on other types of roads and 42.0% on railways.

We did not detect any obvious inter-annual trends in vehicle collisions in the study area, except for increased mortality in Croatia during 2008-2010, which could be connected with construction of new highways in this country. Seasonal dynamics is characterized by two peaks of vehicle collisions, which occur in late spring (May-June) and early autumn (August-October) and concur with the mating period and period of hyperphagia.

For Croatia, we observed relatively equal sex ratio among bears killed in vehicle collisions (proportion of females: 48.9%), while in Slovenia the ratio was male-biased (proportion of females: 44.9%). In both countries the median age was notably higher in females (Slovenia: 2.6 years; Croatia: 2.3 years) compared to males (Slovenia: 1.3 years; Croatia: 1.5 years). In respect to the reconstructed population demographic structure in Slovenia we noted for females general decrease in vehicle collisions with age, while for males proportion of bears killed by vehicles increased among one- and two-year old animals, which corresponds to the age of dispersal. However, we don't exclude possibility that this increase in one- and two-year olds could be connected with increased use of anthropogenic food sources along the transport infrastructure by this age group.

Model results for the Alpine part of the bear population in Slovenia indicate that average annual mortality (19.6-20.5% or 8.8-9.3 dead bears/year) exceeds average annual reproduction (15.8 % or 7.1 born bears/year). Vehicle collisions represent 24.2-27.7% of recorded mortality in the region. According to the modelling results, Alpine part of the population would in case of closed population decline annually for 3.7-4.5%. This indicates that currently Alpine part of the population is not self-sustainable (i.e. it represents a population sink) and that it can in current situation survive only with constant inflow of new bears from the core area on the other side of the Ljubljana-Nova Gorica highway. Model also suggests that demographic self-sustainability of the Alpine part of the population and thus increased opportunities for natural expansion into the Alps could be attained already by preventing all mortality caused by vehicle collisions. However, this will be difficult to achieve in practice and therefore there is a need to reduce also other causes of mortality (among which the legal hunting is the most important one) or/and increase the reproduction. In order to enable reduction of hunting, which is in this region connected mostly with removal of problem bears, it is first required to reduce human-bear conflicts and improve attitudes towards bears among local inhabitants. Reproduction could be increased mainly with increased proportion of females in the region, which is mostly linked to the connectivity between the Alpine periphery and the core area in Dinaric Mountains. This is primarily connected with improving currently poor permeability of the Ljubljana-Nova Gorica highway.

1 INTRODUCTION

Nowadays humans are the main cause of brown bear mortality (Swenson, 2000; Jerina & Krofel 2012). Such anthropogenic mortality includes vehicles collisions on roads and railways which cause an important part of bear mortality in Europe (Huber et al., 1998; Kusak et al., 2000; Kaczensky et al., 2003; Krofel et al., 2012) as well as in North America (Wooding & Hardisky, 1994; Gibeau & Herrero, 1998). In Slovenia and Croatia, vehicle collisions are the second most important, following legal hunting, cause of bear mortality in these two countries (Huber et al., 1998; report Conservation of large carnivores in Slovenia (*Ursus arctos*), Phase 1).

Besides causing mortality, vehicle collisions may also have indirect negative influences on the conservation status of the bear population, for example by reducing the gene flow and reducing functional connectivity of the landscape by obstructing the dispersal of young bears (LIFE III – Nature – report Action A2). Previous research in Slovenia have recognized as an important obstacle the highway Maribor-Ljubljana-Razdrto-Nova Gorica which divides the Slovenian bear population into two demographic areas, namely the Alpine part (NW part of Slovenia) with a low abundance, low density and the sex ratio in favour of males and the southern part (Dinaric part of Slovenia) with higher abundance, density and sex ratio in favour of females (Skrbinšek et al., 2008). This could impede establishment of a vital, well-connected Alpine-Dinaric-Pindos metapopulation and thus have an important impact on the conservation status of the brown bear on European level. The Slovenian part of the bear population is also the only potential source for a natural re-colonization of the Alps (Kaczensky et al., 2003).

Despite previous research on bear vehicle collision in Slovenia and Croatia (Huber et al., 1998; Jerina & Krofel, 2012; Krofel et al., 2012), it is so far not yet known if and how vehicle collisions affect brown bear expansion into the Alpine area. Also, there have also been considerable changes in transport infrastructure since the last studies have been published (e.g. building of highways in Gorski kotar and Lika in Croatia) and until now no research has simultaneously analysed bear mortality at the transboundary level. In the last few years a significant amount of new data has been gathered which enables more accurate analyses than ever before. An in-depth analysis of vehicle collisions on the aforementioned areas by using the latest data is also a prerequisite for a successful execution of the C4 action of this project which will contribute with concrete measures to decreased traffic-related bear mortality.

The purpose of the analysis presented in this report is 1) to analyse the extent of mortality of the Slovenian-Croatian bear population due to vehicle collisions on roads and railways in comparison to other causes of bear mortality, 2) to determine the age and sex structure of bears killed in vehicle collisions, 3) to study the temporal trends (inter-annual and seasonal) of vehicle collisions and 4) to verify to what extent vehicle collisions are connected to the dispersal

behaviour in younger males. Furthermore, 5) for the Slovenian population for which accurate data on the size and demographic structure of the existing population are available, we also assessed the importance of vehicle-caused mortality for individual sex and age categories and 6) assessed the importance of vehicle collisions from the standpoint of bear population expansion into the Alps.

2 MATERIAL AND METHODS OF WORK

We focused on Slovenia and Croatia and in this report we often refer to the Slovenian-Croatian population, although we are aware that these bears are only a part of the larger, Alpine-Dinaric-Pindos brown bear population.

We included in the analysis only the detected removal of bears. Part of mortality is represented by the undetected mortality (undiscovered illegal hunting and natural mortality) for which accurate data was not available and therefore we could not include it in the analyses. Nevertheless, we believe that it does not significantly influence the results of our analyses, because the data obtained in previous telemetric research and by modelling have shown that the percentage of undetected bear mortality is low (Jerina & Krofel 2012; Krofel et al., 2012). However, we included in some analyses the assessment of the proportion of unregistered mortality in Slovenia (27%; Jerina & Krofel 2012).

2.1. Data on detected bear removal

2.1.1. Slovenia

For the analysis of bear mortality due to vehicle collisions on roads and railways in Slovenia data was obtained from the Central register of large carnivores for Slovenia for the period 2004-2012 when the recorded removal was 891 bears. Among them for 21 (2.4%) bears reliable data on sex was not available and so the data on 870 removed bears was used in the analyses. For the analysis of the annual vehicle collision dynamics for the total Slovenian-Croatian population we used data on 603 removed bears in the period 2005-2010 which is consistent with the period with available data for Croatia.

According to the type of removal we divided the data into three groups: hunting (regular, irregular, unjustified shooting), vehicle collision (railroads, highways, other roads) and other (disease, death, capture of live animals for the purpose of relocation and other).

Depending on the geographic area we divided locations of vehicle collisions according to the Maribor-Ljubljana-Nova Gorica highway which represents an important obstacle for bear transitions and divides the Slovenian part of bear population into two demographic areas. For the core area we regarded the area south of the highway, and for the Alpine area we regarded area north of the highway, and for the »HW category« we regarded bears removed on the highway itself.

The age of removed bears was calculated on the assumption that all bears were born 1 February, and for the calculation we used data from the analysis on the basis of cementum annuli counting (Jerina & Krofel, 2012).

2.1.2. Croatia

For the analysis of bear mortality due to vehicle collisions on roads and railways in in Croatia we used data on removed bears in the period 2005-2010 during which 535 bears were removed. Due to insufficient data on sex (N=26) and age (N=5) we included in the analysis for Croatia data on 504 removed bears.

The aggregation of data into categories and bear age calculation for Croatia was done in the same manner as for Slovenia.

2.2. Data analysis

2.2.1. Analysis of bears killed in vehicle collisions in Slovenian-Croatian population

In the analysis of vehicle collisions we demonstrated the data on the type of transport infrastructure in two manners. Firstly, we showed traffic accidents on all three types of transport infrastructure – highways, other roads and railways, and then we combined vehicle collisions on highways and other roads into a single category of roads. All three types of transport infrastructure were shown in the informative overview of vehicle collisions and in the overview of the seasonal dynamics of vehicle collisions. In the analysis of the sex and age structure we used the combined data on vehicle collisions on roads, as we assume that the cause of vehicle collisions with bears on roads and highways was the same (i.e. dispersal) and a larger sample size gave more reliable results.

In the analysis of the sex and age structure we also verified whether patterns of vehicle collisions change according to the dispersal period. For this purpose we divided the bears into three age categories: pre-dispersal (up to and including 15 months of age), dispersal (the start of the 16th month of age up to the end of the 39th month of age) and the post-dispersal period (after the 40th month of age). In bears, males are usually the ones that disperse away from their mother's home range in search of a suitable habitat, while females often establish their own home range within or in the close proximity of their mother's area (Støen et al. 2006). This is why we carried out an analysis separately for both sexes and thereby tried to distinguish the influence of dispersal on vehicle collision frequency.

The age of removed bears was between 0 and 25 years. The years represent the bear's age upon death, for example bears aged 0 are bears up to the age of 1 year. Due to the small number of bears above the age of 8 years, we combined the bears above this age into three categories: 9-10 years, 11-12 years and > 13 years. The influence of the age structure of bears with the detected mortality due to vehicle collisions was compared between both sexes.

For the Slovenian part of the bear population (data from 2004-2012) we calculated the mortality rate due to vehicle collisions, according to the reconstructed status of living bears in the population according to sex and age. The reconstruction of population size, age and sex structure, mortality and the birth rate was carried out as part of the report on brown bear removal in Slovenia (Jerina & Krofel 2012). The data on the structure of living bears in the population was calculated according to the absolute number estimate (N=500) and the sex ratio estimated in the genetic analysis (proportion of females: 56%; Skrbinšek et al., 2008). Within the analysis of the mortality rate due to vehicle collisions we used all available data on vehicle collisions with bears in Slovenia in 2004-2014 (N=142) and for individual demographic bear categories we calculated the proportions of bear mortality due to vehicle collisions according to the reconstructed population structure. Due to a small number of vehicle collisions with animals aged above 5 years we formed two age categories in which we joined 1) bears killed in vehicle collisions aged 6-10 years, and 2) bears older than 10 years. The data on bears aged 0 to 5 years are shown for each year individually – the years represent the age when the bears died, for example bears aged 0 represent bears < 1 year of age.

2.2.2. Influence of vehicle collisions on the Alpine part of the bear population

For the analysis of bear mortality due to traffic accidents on the highway Maribor-Ljubljana-Nova Gorica and its influence on the expansion of the bear population we used all available data for removed bears in Slovenia for the period 2001-2012.

For the calculation of the demographic self-sustainability of the Alpine part of the bear population in Slovenia we firstly assumed that this part of population is isolated from the rest of the bear population in the central part and modelled the population dynamics according to the postulate. Thus we assessed to what extent the Alpine part of the population depends on the immigration from the core area in the Dinaric Mountains. For the calculation we used the data on the population's birth rate and mortality on the level of the entire population (Jerina & Krofel, 2012) while taking into account the local sex structure of the bear population in this area (Skrbinšek et al., 2008). Jerina & Krofel (2012) determined by modelling (models with included estimated of unrecorded bear mortality) that the average annual population birth rate of female bears (annual birth rate) in Slovenia is 28%. Skrbinšek et al. (2008) calculated with the help of a non-invasive genetic study on the basis of population density that the sex ratio in Slovenia is shifted in favour of females (proportion of females=56%; N_{total}=434), while in the Alpine area it is shifted in favour of males (proportion of females=30%).

The abundance of bears for the NW part of Slovenia was obtained from the estimation for the absolute bear population density in Slovenia (with the estimation N=500; Jerina et al. 2013) and

assessed that 91% (N=455) of the bear population in Slovenia is south of the highway, and 9% (N=45) north of the highway.

For the analysis of the influence of vehicle collisions on the Alpine part of the population we combined all collisions of bears with vehicles (roads, highways, railways) in one category (vehicle collisions). For the calculation of the total (recorded and unrecorded) bear removal in Slovenia we used data in the recorded bear removal in 2004-2012 and the estimation of the unrecorded removal share in Slovenia (27%; Jerina & Krofel 2012).

During the period 2004-2012 five cases of vehicle collisions with bears were recorded on the highway Ljubljana-Nova Gorica. For these bears we do not have information from which part of Slovenia they originated or if these were bears in dispersal that were probably in the process of migrating to the northern side of the highway or if these were resident bears in that area. For this reason we carried out two analyses that cover both possible extreme scenarios. Firstly, we assumed that all bears killed in vehicle collisions were dispersing from south to north (in this case we used the value 54 for bear mortality in the Alpine area), while the other estimation was based on the assumption that all bears killed in vehicle collisions on the highway were the residents of a narrow area on both sides of the highway, whereby we posited that they spent an equal amount of time south and north of the highway (in this case the used the value 51.5 for the bear mortality in the Alpine area).

The demographic self-sustainability of the Alpine part of the bear population was calculated with the help of a simplified age non-structured model of the size change in a population. Under the assumption of geometric growth we calculated on the basis of data on potential birth rate (b_t) and mortality (d_t) in the population the net change (increment) of the population size (R) in one year and thus estimated the self-sustainability of this part of population. R is calculated as the difference between the number of animals that were born and the number of animals that died in a population in one year. In order to estimate the importance of traffic-caused mortality for the expansion of the brown bear in the Alpine region we also calculated the net increment of the bear population in the NW part of Slovenia for the case if all bear mortality due to traffic accidents could have been prevented.

3 RESULTS

3.1. IMPORTANCE OF TRAFFIC-CAUSED MORTALITY IN COMPARISON TO OTHER CAUSES OF REMOVAL IN THE SLOVENIAN-CROATIAN BEAR POPULATION

3.1.1. Overview of causes of bear removal in Slovenia and Croatian and comparison between the countries

The most important cause of the detected bear mortality in Slovenia (for the period 2004-2012) and in Croatia (for the period 2005-2010) was hunting with 78.4% ($N_{hunting}$= 1077). During the same period in Slovenia and Croatia 234 vehicle collisions with bears were reported which represents 17.0% of the recorded mortality.

Table 1: Overview of the average number of annually recorded causes of bear mortality for Slovenia (2004-2012) and Croatia (2005-2010).

	Bears removed per year **SLOVENIA**	**%**	Bears removed per year **CROATIA**	**%**	Number of all bear removed **SLO & HR**	**%**
Hunting	87,5	80,6	75,4	74,8	1077	78,38
Other	3,5	3,22	7	6,94	63	4,59
Vehicle collisions	17,75	16,32	18,4	18,25	234	17,03
Roads	*10*	*9,2*	*9,8*	*9,72*	129	9,39
Railways	*7,75*	*7,12*	*8,6*	*8,53*	105	7,64
Total	108,7	100	100,8	100	1374	100

In the study period 2005-2010 there were 181 registered vehicle collisions with bears in Slovenia and Croatia. In Slovenia the majority (53.9%; N=48) of total 89 cases of detected vehicle-caused bear mortality occurred on local roads, 9.0% (N=8) on highways and 37.1% (N=33) on railways. In Croatia the majority, 53.3% (N=49) of the total of 92 cases of detected bear mortality occurred on roads (26.1%, N=24 on highways and 27.2%, N=2) on other roads) and 46.7% (N=43) on railways.

In total 1107 bears were detected removed from nature in Slovenia and Croatia in the period 2005-2010, annually on average 185 bears. The highest number of removed bears was in 2010 (N=221, the proportion of females = 37.1%; Figure 1). 146 animals were on average annually removed by hunting (average proportion of females = 35.5%) and approximately 30 animals were due to vehicle collisions (average proportion of females = 45.5%). In 2006, the number of

bears that died in vehicle collisions in Slovenia and Croatia was the highest (N=38; proportion of females=63.2%). (Figures 1 and 2)
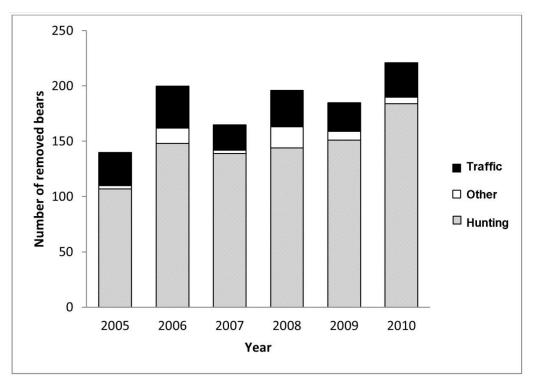

Figure 1: Number of removed bears in Slovenia and Croatia for individual calendar years in the period 2005-2010 for the three categories of removal.
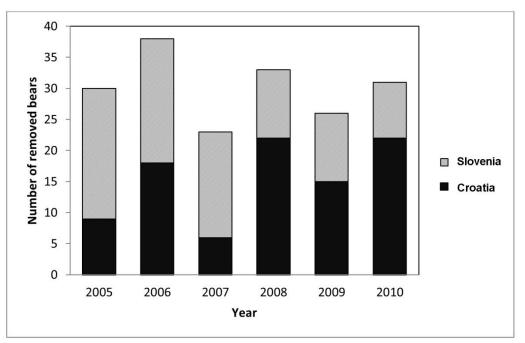

Figure 2: Comparison between Slovenia and Croatia in number of bears that died in vehicle collisions per year in the period 2005-2010.

3.1.2 Overview of the seasonal vehicle collision dynamics in Slovenia and Croatia and comparison between the countries

In Croatia in the period 2005-2010 there were more annually detected vehicles collisions on highways compared with Slovenia (the period 2004-2012). The highest number of vehicle collisions on highways in Croatia in Slovenia combined occurred in May and August (both months: 19.5%, N=7), followed by September (16.7%, N=6). (Figure 3)
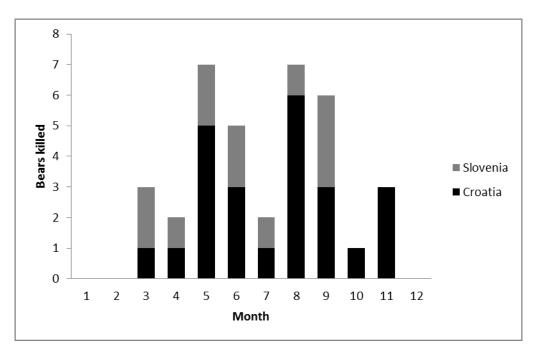

Figure 3: Number of bears killed per month in vehicle collisions on highways in Slovenia (2004-2012) and Croatia (2005-2010).

In Slovenia in the period 2004-2012 there were substantially more vehicle collisions detected on non-highway roads in comparison to Croatia. The highest number of vehicle collisions on the roads in Croatia and Slovenia occured in October (21.4%, N=21), followed by June and September (both months: 15.3%, N=15) (Figure 4).
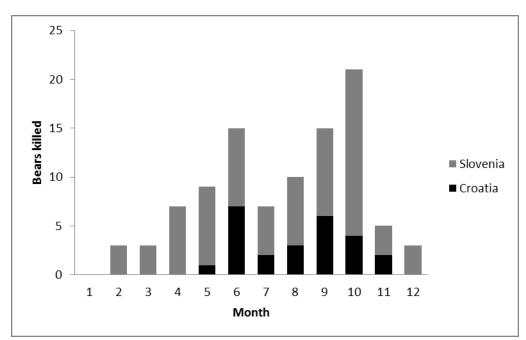
Figure 4: Number of bears killed per month in vehicle collisions on main and other roads in Slovenia (2004-2012) and Croatia (2005-2010).

The highest number of all detected vehicle collisions in railways in Slovenia and Croatia was cumulatively in September and October (both months: 16.19%, N=17), followed by June (15.23%, N=16) and May (14.28%, N=15). (Figure 5)
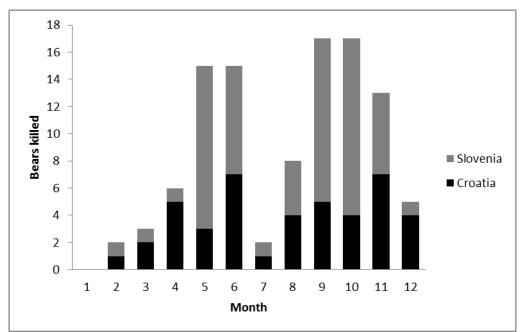

Figure 5: Number of bears killed per month in vehicle collisions on railways in Slovenia (2004-2012) and Croatia (2005-2010).

3.1.3 Analysis of the sex and age structure of bears removed from nature in Slovenia and Croatia (2005-2010)

Among the bears removed in the period 2005-2010 males predominated in both Slovenia and Croatia. The difference between sexes was lower (proportion of females: 44.4%) in Slovenia compared with Croatia (29.8%). The largest difference in the sex ratio of removed bears in the two countries was in the category of legal hunting: In Croatia (proportion of females: 23.9%) fewer females were hunted than in Slovenia (proportion of females: 43.8%).

The median age of removed bears was higher in Croatia (females: median=4.8 years, N=90; males: median=4.7 years, N=287) than in Slovenia (females: median=2.7 years, N=217; males: median=2.7 years, N=279). The proportion of male removals within the category other is higher in Croatia (proportion of females in Croatia: 42.85%; proportion of females in Slovenia: 61.11%) than in Slovenia.

While in Croatia a comparable number of females and males in a population were removed due to vehicle collisions (proportion of females: 48.9%), in Slovenia the documented sex ratio was male-biased (proportion of females: 44.9%). The median values of the ages of males and females killed in vehicle collisions are similar in both countries. In both countries the age of bears killed in vehicle collisions is lower than of bears removed for other reasons. The median age of bears that died in vehicle collisions in Slovenia was lower (1.3 years) for males compared to females (2.6 years). A similar trend can be observed in Croatia, although the difference is somewhat smaller. In both countries trains killed a larger share of males than females, but the countries differ in the median age. (Table 2).

Table 2: Overview of the sex and age structure of recorded bears removed from nature between 2005 and 2010 in Slovenia and Croatia. The values in parenthesis show the median bear age. The proportions represent the sex ratio for individual types of removal separately for each country.

	Croatia (N=504, 100 %)				Slovenia (N=603, 100 %)			
	FEMALES	%	MALES	%	FEMALES	%	MALES	%
Hunting	90 (4,8)	23,9	287 (4,7)	76,1	217 (2,7)	43,75	279 (2,7)	56,25
Other	15 (4,5)	42,85	20 (1,9)	57,14	11 (3,7)	61,11	7 (3,6)	38,88
Vehicle collisions	45 (2,3)	48,91	47 (1,5)	51,08	40 (2,6)	44,94	49 (1,3)	55,05
Railway	*20 (1,8)*	*46,51*	*23 (2,4)*	*53,48*	*13 (2,7)*	*39,39*	*20 (1,4)*	*60,60*
Roads	*25 (2,6)*	*51,02*	*24 (1,4)*	*48,97*	*27 (2,4)*	*48,21*	*29 (1,3)*	*51,78*
Total	150	29,76	354	70,24	268	44,44	335	55,56

3.1.4. Analysis of the sex and age structure of bears killed in vehicle collisions

3.1.4.1. Overview of the sex and age structure of bears killed in vehicle collisions in Croatia (2005-2010) and Slovenia (2004-2012)

The highest number of bears killed in vehicle collisions were younger than 1 year (32.6%, N=42 for roads; 29.5 %, N=31 for railways) and the number of killed bears deceased with bear age. Among younger bears more males died in vehicle collisions, but females started to dominate after age of 3 years (Figures 6 and 7).
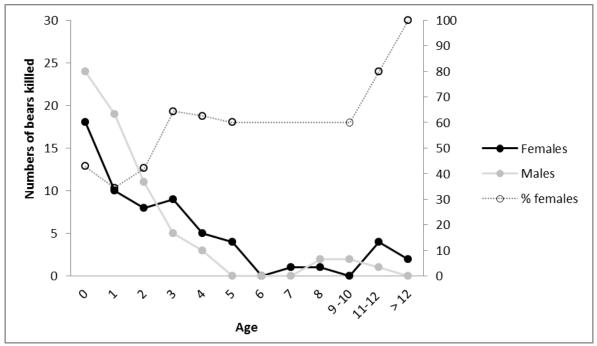

Figure 6: Number of detected male and female bear mortality according to their age due to vehicle collisions on roads in Slovenia (2004-2012) and Croatia (2005-2010). Years represent bear age upon their death, for example bears aged 0 were bears aged < 1 year. Age > 12 includes the bear age between the 13th and 25th year of age. The proportion of detected female mortality in a specific age is also shown. Due to a small number of females killed in vehicle collisions aged 5 to 10 years a category of females (5-10 years) was formed which included all females aged between 5 and 10 years of age.
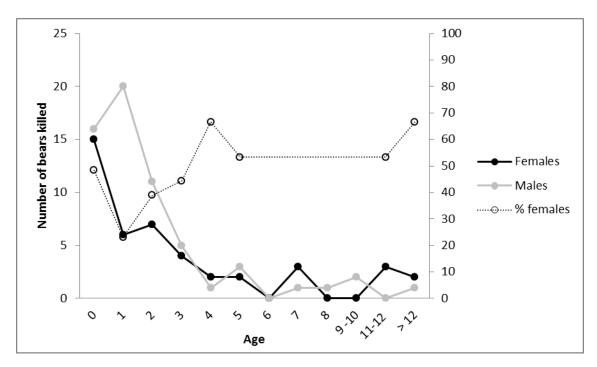
Figure 7: Detected male and female bear mortality according to their age due to vehicle collisions on railways in Slovenia (2004-2012) and Croatia (2005-2010).

3.1.4.2. Mortality of males due to vehicle collisions according to the dispersal period in comparison to other reasons for removal from nature

3.1.4.2.1. Roads

The highest mortality rate due to legal hunting was observed among males in the post-dispersal period (N=312, 89.1%), while males with the lowest mortality share, 46.5% (N=59) belonged to the pre-dispersal group. Out of the 67 detected cases of male mortality due to vehicle collisions on roads the males in the pre-dispersal period had the highest mortality rate compared to other two dispersal periods. (Table 3). The largest proportion of males killed in vehicle collisions on roads was in the pre-dispersal period (48%, N=32). (Figure 8). The highest number of bears in dispersal period killed on roads was in September (20.8%) (Figure 9).

Table 3: Number of detected mortality rate due to vehicle collisions in individual categories of males in Slovenia (2004-2012) and Croatia (2005-2010) according to the dispersal period: pre-dispersal period (up to 15 months of age), dispersal (between 16 and 39 months of age), post-dispersal period (after the 40th month of age). The removal proportion according to other causes for removal shows the proportion of recorded vehicle collisions with bears on roads in relation to other causes (legal hunting, other, vehicle collisions on railways) within an individual dispersal category. The highest proportion of removal is also shown.

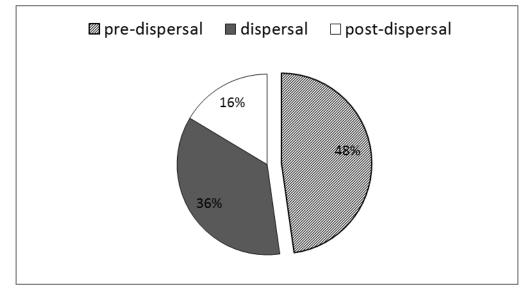| Period:	Croatia (N)	Slovenia (N)	Total	% of all removals	
1. pre-dispersal	12	20	*32*	*25,19 %;*	*hunting: 46,45 %*
2. dispersal	10	14	*24*	*6,53 %;*	*hunting: 85,83 %*
3. post-dispersal	2	9	*11*	*3,14 %;*	*hunting: 89,14 %*
Total	*24*	*43*			

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Figure 8: Proportion of male removals due to vehicle collision on roads in Slovenia (2004-2012) and Croatia (2005-2010) according to the dispersal period: pre-dispersal (up to 15 months of age), dispersal (between the 16th and 39th month of age), post-dispersal (after the 40th month of age).
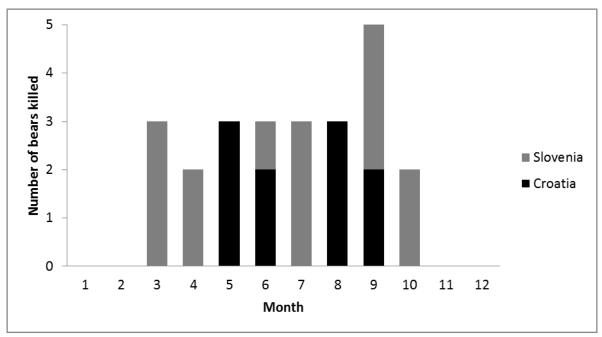

Figure 9: Monthly vehicle collisions with bears in the dispersal period (between the 16th and 39th month of age) on the roads in Slovenia (2004-2012) and Croatia (2005-2010).

3.1.4.2.2 Railways

Among 61 detected cases of male mortality due to vehicle collisions on railways the males in the pre-dispersal period had the highest mortality rate (48%, N=32) compared to other two dispersal periods. (Table 4, Figure 10). The highest number of bears in dispersal period killed on railways was in June (22.72%) (Figure 11).

Table 4: Detected mortality due to vehicle collisions on railways in individual categories of males in Slovenia (2004-2012) and Croatia (2005-2010) according to the dispersal period: pre-dispersal (up to 15 months of age), dispersal (between the 16th and 39th month of age), post-dispersal (after the 40th month of age). The proportion of removal in relation to other causes for removal is shown by the proportion of all recorded vehicle collisions with bears on railways according to other causes (hunting, other, vehicle collisions on roads) within an individual dispersal category. The largest proportion of removal is also shown.

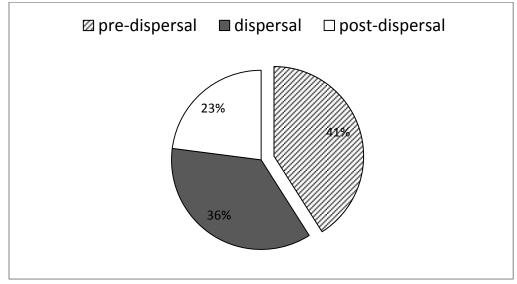| Period:	Croatia (N)	Slovenia (N)	Total	% of all removals	
1. pre-dispersal	9	16	25	19,7 %;	hunting: 46,4 %
2. dispersal	6	16	22	6,0 %;	hunting: 85,8 %
3. post-dispersal	8	6	14	4,0 %;	hunting: 89,1 %
Total	23	38			

Figure 10: Proportion of the removal of males due to vehicle collision on railways in Slovenia (2004-2012) and Croatia (2005-2010) according to the dispersal period: pre-dispersal (up to 15 months of age), dispersal (between the 16th and 39th month of age), post-dispersal (after the 40th month of age).
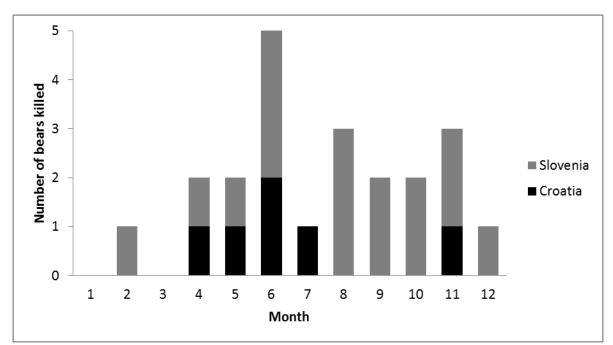
Figure 11: Number of male bears killed monthly in vehicle collisions in the dispersal period (between the 16th and 39th month of age) on railways in Slovenia (2004-2012) and Croatia (2005-2010).

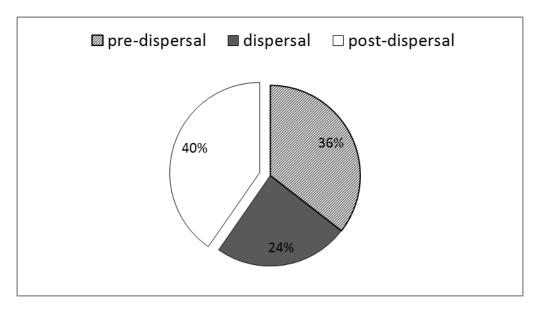### 3.1.4.3. Removal of females due to traffic accidents
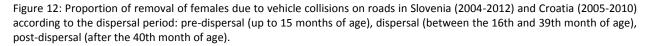
3.1.4.3.1. Roads

The females with the highest mortality rate due to legal hunting were in the dispersal period (N=199, 85.04%), the females with the lowest mortality rate, 50% (N=46) were part of the pre-dispersal group. Out of the 62 detected cases of females killed on roads, the highest number was among bears from pre-dispersal period. (Table 5). The largest proportion of females killed in vehicle collisions on roads was in the pre-dispersal period (40%). (Figure 8). The highest number of bears in dispersal period killed on roads was in October (26.7%, N=4), followed by May and August (both with 20%, N=3; Figure 13).

Table 5: Number of vehicle collisions on roads for female categories in Slovenia (2004-2012) and Croatia (2005-2010) according to the dispersal period: pre-dispersal (up to 15 months of age), dispersal (between the 16th and 39th month of age), post-dispersal (after the 40th month of age). The removal proportion in relation to other causes of removal shows the share of all recorded vehicle collisions with female bears on railways in relation to other reasons (legal hunting, other, vehicle collisions on roads) within individual dispersal categories. The largest share of removal is also shown.

Period:	Croatia (N)	Slovenia (N)	Total	% of all removals	
1. pre-dispersal	6	16	22	24,0 %;	hunting: 50,0 %
2. dispersal	7	8	15	6,4%;	hunting: 85,0 %
3. post-dispersal	12	13	25	12,3%;	hunting: 71,6 %
Total	25	37			

Figure 12: Proportion of removal of females due to vehicle collisions on roads in Slovenia (2004-2012) and Croatia (2005-2010) according to the dispersal period: pre-dispersal (up to 15 months of age), dispersal (between the 16th and 39th month of age), post-dispersal (after the 40th month of age).
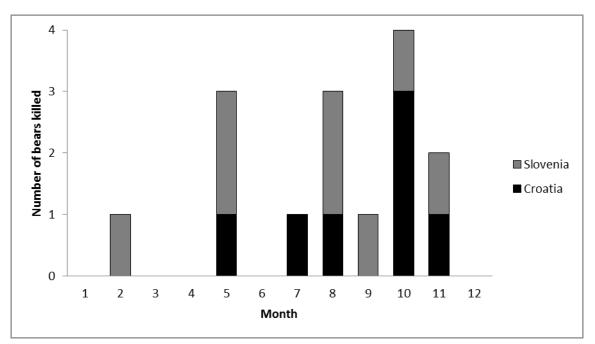

Figure 13: Number of female bears killed monthly in vehicle collisions in the dispersal period (between the 16th and 39th month of age) on roads in Slovenia (2004-2012) and Croatia (2005-2010).

3.1.4.3.2. Railways

Out of the 44 detected cases of females killed on railways, the highest number (N=18; Table 6) was among bears from pre-dispersal period. (Table 6; Figure 14). The highest numbers of bears in dispersal period killed on railways were in September and October (each 25%, N=3) (Figure 15).

Table 6: Number of vehicle collisions on railways for female categories in Slovenia in Slovenia (2004-2012) and Croatia (2005-2010) according to the dispersal period: pre-dispersal (up to 15 months of age), dispersal (between the 16th and 39th month of age), post-dispersal (after the 40th month of age). The proportion of removal in relation to other causes for removal shows a proportion of all recorded vehicle collisions with female bears on railways according to other causes for removal (legal hunting, other, vehicle collisions on roads) within individual dispersal categories. The largest proportion for removal is also shown.

Period:	Croatia (N)	Slovenia (N)	Total	% of all removals	
1. pre-dispersal	7	11	18	19,6 %;	hunting :50,0 %
2. dispersal	7	5	12	5,1 %;	hunting:85,4 %
3. post-dispersal	6	8	14	6,7 %;	hunting: 71,6 %
Total	20	24			

Figure 14: Share of removal of females due to vehicle collisions on roads in Slovenia (2004-2012) and Croatia (2005-2010) according to the dispersal period: pre-dispersal (up to 15 months of age), dispersal (between the 16th and 39th month of age), after dispersal (after the 40th month of age).

Figure 15: Number of female bears killed monthly in vehicle collisions in the dispersal period (between the 16th and 39th month of age) on railways in Slovenia (2004-2012) and Croatia (2005-2010).

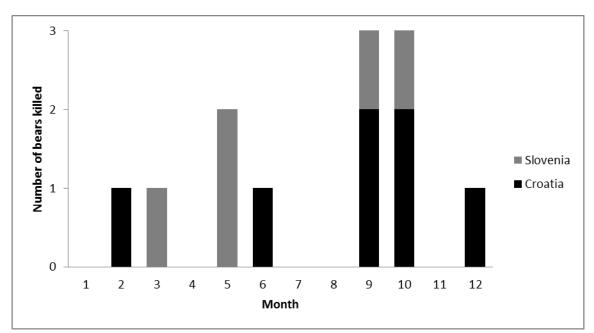## 3.2 ANALYSIS OF VEHICLE COLLISIONS ACCORDING TO THE EXISTING BEAR POPULATION STRUCTURE

Table 7: Sex and age structure of living bears in the population according to the proportion and estimated number of animals under the assumption of population size (N=500) (Jerina & Krofel, 2012).

Age	% males	% females	N males	N females	
0	0.146	0.144	73	72	145
1	0.099	0.107	50	53	103
2	0.064	0.077	32	39	71
3	0.041	0.057	21	28	49
4	0.027	0.044	14	22	35
5	0.020	0.034	10	17	27
6	0.015	0.027	7	14	21
7	0.010	0.021	5	11	16
8	0.008	0.016	4	8	12
9	0.006	0.011	3	6	9
10	0.003	0.009	2	5	6
11	0.001	0.007	0	3	4
12	0.000	0.004	0	2	2
13	0.000	0.002	0	1	1
14	0.000	0.001	0	0	0
15	0.000	0.000	0	0	0
	44 %	**56 %**	220	280	500

3.2.1. Bear mortality rate due to vehicle collisions

According to available data the most sensitive demographic part of the population are older females. However, it should be taken into account that for this group the abundance estimate is probably less reliable and perhaps underestimated (consequently the mortality rate is probably overestimated). Otherwise among female bears the mortality rate due to vehicle collisions generally decreases with age, both in vehicle collisions on roads and on railways. A different pattern is observed in males where an increased susceptibility for vehicle collisions is apparent in one- and two-year-old males which corresponds to the dispersal period. This is especially apparent for railways. (Figures 16-18)

Figure 16: Proportion of the bears killed in vehicle collisions in Slovenia (2004-2012) for individual sex and age categories according to the reconstructed status of the number of living bears in the population. The years represent bear age upon their death. Due to a small number of bears killed in vehicle collisions at the age above 6 years we combined the data for these bears into the categories 6-10 years and > 10 years.
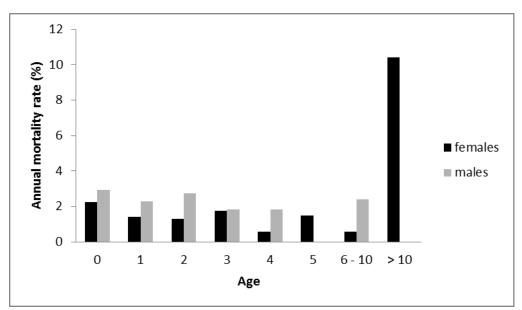
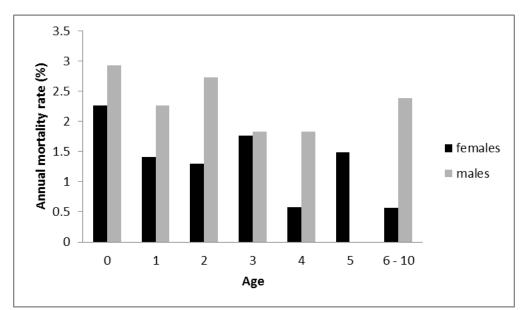Figure 17: Proportion of the bears killed in vehicle collisions on roads for individual sex and age categories according to the reconstructed status of the number of living bears in the population.
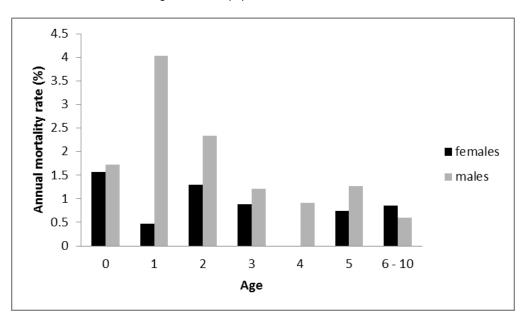

Figure 18: Proportion of the bears killed in vehicle collisions on railways for individual sex and age categories according to the reconstructed status of the number of living bears in the population.

3.3. TRAFFIC-CAUSED BEAR MORTALITY ON THE HIGHWAY LJUBLJANA-NOVA GORICA AND THE INFLUENCE ON THE ALPINE PART OF THE POPULATION

In Slovenia during the period 2004-2012 nine cases of bear mortality on highways were detected, of which five occurred on the highway Ljubljana-Nova Gorica. All these animals were male, their age median was 2.2 years.

The estimated average birth rate of the population (b_t) north of the Ljubljana-Nova Gorica highway was estimated to 15.8% or in average 7.1 bears born per year.

During the period 2004-2012 in the Alpine area (i.e. north of the Ljubljana-Nova Gorica highway, also taking into account vehicle collisions on the highway itself) 54 bear removals were recorded, out of which 15 were vehicle collisions (51.5 removals and 12.5 vehicle collisions if half of vehicle collisions on the highway are taken into account). Vehicle collisions thus represent 24.2-27.7% of the recorded mortality. The proportion of females killed in vehicle collisions was 20-24%, and the age median was 2.2 years. All females killed in vehicle collisions in the northern part of Slovenia were killed on roads other than highways. The highest proportion of mortality in this area was legal hunting with 38 bears killed by legal hunting (70.3-73.8% of recorded mortality; proportion of females: 18.5%; median age: 2.75 years). By taking into account estimated proportion unrecorded bear mortality (27% of all mortality), the entire bear removal (recorded and unrecorded) in the northern part of Slovenia in the period 2004-2012 was estimate to 70-74 bears. When taking into account the above assumptions on average 8.8-9.2 bears per year die in the Alpine region, which represents 19.6-20.5% mortality (d_t).

The estimates for the northern part of the Slovenian bear population indicate that the average annual mortality exceeds the average annual birth rate in the region. Assuming a closed population the annual net increment of the population (R) would be negative in both scenarios, i.e. when all five bears killed in vehicle collisions on highways are considered (b_t=0.158, d_t=0.205, R= -0.046, λ=0.954) as in the scenario when assuming all of these bears were residents (b_t=0.158, d_t=0.195 R= -0.037, λ=0.963). In the case of a closed population it would decline each year for 3.7-4.5%. This means that the Alpine part of the population in Slovenia is demographically not self-sustainable (it represents a sink for the population) and it can in long-term survive only by constant influx of new animals from the core area of the population south of the highway.

If all traffic-caused bear mortality in the Alpine area would be prevented, the recorded mortality would decrease to 39 bear removals. By taking into account the unrecorded mortality rate the entire removal would be 53.4 bears or 6.7 dead bears annually and a mortality rate (d_t) 14.8%. The average annual population mortality in this case would not exceed the average

annual population birth rate (bt=0.16) and consequently the annual net increment of the population would be positive (R=0.01, λ=1.01) and the area would no longer be a population sink and population would be able to demographically sustain itself.

4 DISCUSSION

Traffic-caused mortality of the Slovenian-Croatian bear population is relatively high (17.0% of all recorded mortality) and after legal hunting (78.4%) the second most important cause of recorded bear mortality. Despite the high mortality rate due to vehicle collisions it must be emphasized that the latter is in principle taken into account when determining the annual quota for bear hunting, so that both forms of mortality are compensated in accordance with the principles of the adaptive management.

During the period 2005-2010, 181 bears were recorded being killed in vehicle collisions in Slovenia and Croatia. In Slovenia vehicle collisions on roads other than highways predominated, while in Croatia the proportion of vehicle collisions on these roads were comparable with highways. A significantly higher proportion of vehicle collisions on highways in Croatia than in Slovenia could be connected to easier accessibility of anthropogenic food sources on highway rest stops in the area of Gorski Kotar which attract bears to the vicinity of highways and are connected to a third of all vehicle collisions with bears on Croatian highways (Huber et al. 1998). Feeding on anthropogenic food sources along roads was also recorded in Slovenia (for example on main roads in the Notranjska region; Jerina et al. 2012), but it is apparently not as common as on highways in Croatia. In Croatia the proportion of vehicle collisions on railways was also higher. Also collisions on railways are supposed to be connected with searching for food (especially for carrion of animals killed by trains as well as corn and other cargo that falls from train wagons; Kaczensky et al., 2002).

The number of bears killed in vehicle collisions in the study area does not show any obvious trends in time (all larger discrepancies between the years are a consequence of differences in annual hunting quotas), but we have noticed certain changes in the years between the two countries. In 2005-2007 vehicle collisions predominated in Slovenia and in 2008-2010 the proportion of vehicle collisions was higher in Croatia. This change could at least partially be contributed to the construction of new highways in Croatia.

The proportion of males among bears killed in vehicle collisions in lower in Croatia compared to Slovenia, which may be connected with male-biased hunting of bears in Croatia, which increases the proportion of females in the surviving population. Also dispersal, which is male-biased in brown bears, may contribute to this difference. Because Slovenia represents the edge of the population where the proportion of dispersing bears is typically higher, this can increase the proportion of males and then become also reflected in the sex-ratio of bears killed in vehicle collisions.

An overview of the season dynamics of vehicle collisions with bears revealed that on highways the highest number of vehicle collisions happened in spring (May) and later summer (August), on main roads in late fall (October), and on railways in spring (May and June) and fall (September, October). Similar results (spring and fall peaks) were observed also in previous studies in both Croatia and Slovenia (Huber et al., 1998; Kaczensky et al., 2003). These results may be explained by two factors. The spring peak of vehicle collisions is most probably connected to the seasonal dynamics of the bear movement activity. According to the telemetry data from Slovenia (Jerina et al., 2012) the movement activity of bears is the highest in May and June which coincides with the peak of the mating period. On the contrary, the movement activity declines in fall (especially in September) which does not coincide with the vehicle collision dynamics. The fall vehicle collision peak is thus most probably connected with intense search for food at that time (so-called hyperphagia which is connected to the accumulation of fat reserves for winter sleep) and the bear's aforementioned approaching to the traffic infrastructure due to the search for anthropogenic food sources and game killed in vehicle collisions.

In comparison to other causes of mortality, younger bears and females are more susceptible for vehicle collisions. According to the absolute number of vehicle collisions in both sexes the highest number of bears killed in vehicle collisions is among cubs, and the number gradually declines with age. But this is mostly a consequence of the structure of the living population which is under strong hunting pressure and consequently only small part of young bears survives adult age (Jerina & Krofel, 2012; Krofel et al. 2012). Similarly, the increasing proportion of females among older bears killed in vehicle collisions is connected mostly with the structure of the population. Due to stronger hunting pressure on adult males in comparison to older females (breeding females are not hunted as part of regular hunting) the structure among older age classes is strongly skewed in favour of females.

From the viewpoint of an individual bear, we get a better insight into the susceptibility for vehicle collisions from the data on traffic-caused mortality rate in respect to the reconstructed population structure (i.e. proportion of bears killed in vehicle collisions for each sex/age class). These results indicate substantial increase in mortality among older females, but we assume that this is mostly a consequence of poorer data on bear abundance for this category which was probably underrated in population models. Since number of bears in this category is small, even a small error in the absolute value can have a large influence on the final results. For the ages up to 10 years, for which the data is more reliable, the female mortality due to vehicle collisions is rather steadily decreasing, which can most probably be explained by the growing experience of older female bears, and in part also possibly with the selection caused by traffic-caused mortality. A different pattern can be observed in males where the susceptibility for vehicle

collisions initially increases and is highest among yearlings and 2-year olds, which is probably connected with dispersal.

To assess to what extent vehicle collisions are connected with dispersal behaviour (i.e. emigration of males away from their natal area and establishing a post-dispersal home range), we firstly analysed the absolute numbers of bear males killed in vehicle collisions in respect to their age according to dispersal period, and the seasonal dynamics of vehicle collisions. This data does not support the assumption that vehicle collisions are importantly connected with dispersal. However, different is shown by data on the traffic-caused mortality rates according to the existing population structure. As mentioned above, these data showed an increase of vehicle collisions among males in the dispersal age which was not observed in females of the same age. Results are thus ambiguous, but we believe that the data on the mortality rate according to categories in relation to the living population are more reliable. Therefore we assume that part of vehicle collisions is connected with dispersal behaviour of bears. Nevertheless, we do not exclude the possibility that the observed increase of the mortality rate in one- and two-year-old males is connected with an increased use of anthropogenic food sources among these bears, especially since the increase in vehicle collisions is much more prominent in railways than in roads.

The Alpine part of the population (i.e. the area north of the Ljubljana-Nova Gorica highway) contains only a small portion of bears in Slovenia and in contrast to other areas the sex ratio in this part of the population is strongly male-biased (Skrbinšek et al. 2008). This reduces reproductive potential and consequently might make this part of the population more vulnerable to traffic-related mortality and strongly dependent on the core area of the population. The results have confirmed this hypothesis and have shown that without vehicle collisions this part of the population would have been demographically self-sustainable. But in the current situation the mortality rate is higher than the birth rate. Mortality is not significantly different from that in the core area, but their birth rate is significantly lower due to small number of females. This is the main reason why this area presents the population sink and is in long-term dependent on the constant influx of animals from the core area of the population.

If the demographic self-sufficiency of the Alpine part of the population in Slovenia is to be ensured and thus the possibilities for further expansion of the brown bear in the Alpine region in neighbouring countries is to be increased, it will be (besides the measures in neighbouring countries) necessary to reduce the mortality rate and/or increase the birth rate in this area. The model has shown that the latter would already be possible by preventing all traffic-related mortality. But this will be impossible to achieve in practice. Probably easier to achieve would be to reduce part of other causes of mortality (the most important among them is currently

hunting) or to increase the birth rate. Before the legal hunting can be reduced it would be crucial to reduce the frequency of human-bear conflicts and increase acceptance of bears among local public. Basically the only option to increase the birth rate would be by increasing the number of females in this area, which is (in addition to managing the population south of the highway) largely connected with the improvement of the connectivity of the Alpine area with the population core in the Dinaric region. In this sense the permeability of the Ljubljana-Nova Gorica likely plays a crucial role.

5 LITERATURE

Benn Bryon, Herrero Stephen. 2002. Grizzly bear mortality and human access in Banff and Yoho national parks, 1971-98. Ursus, 13: 213-221

Gibeau L. Michael, Herrero Stephen. 1998. Roads, rails and grizzly bears in the Bow River Valley, Alberta. proceedings International Conference on Ecology and Transportation, Florida, Department of Transportation, Talahassee.

Huber Djuro, Kusak Josip, Frkovic Alojzije. 1998. Traffic kills of brown bears in Gorski Kotar, Croatia. Ursus, 10: 167-171

Jerina & Krofel. 2012. Monitoring odvzema rjavega medveda iz narave v Sloveniji na osnovi starosti določene s pomočjo brušenja zob: obdobje 2007-2010. Končno poročilo. Naročnik: Ministrstvo RS za okolje in prostor, Agencija RS za okolje, 35 str.

Jerina Klemen, Krofel Miha, Stergar Matija, Videmšek Uroš. 2012. Preučevanje dejavnikov habituacije rjavega medveda na človeka u uporabo GPS telemetrije. Končno poročilo. Univerua v Ljubljani, BF, 18 str.

Kaczensky Petra, Knauer Felix, Krže Blaž, Jonozovič Marco, Adamič Miha, Gossow Hartmut. 2003. The impact of high speed, high volume traffic axes on brown bears in Slovenia. Biological Conservation, 111: 191-204

Krofel Miha, Jonozovič Marko, Jerina Klemen. 2012. Demography and mortality patterns of removed brown bears in a heavily exploited population. Ursus, 23 (1):91-103

Kusak Josip, Huber Djuro, Frkovic Alojzije. 2000. The effects of traffic on large carnivore populations in Croatia. Biosfere Conservation 3 (1): 35-39

Mills Scott. 2007. Conservation of Wildlife Populations: Demography, Genetics and Management. Blackwell publishing, 424 str.

Skrbinšek Tomaž, Jelenčič Maja, Potočnih Hubert, Trontelj Peter, Kos Ivan. 2008. Analiza medvedov odvzetih iz narave in genetsko-molekularne raziskave populacije medveda v Sloveniji. Zaključno poročilo, 1.del: Varstvena genetika in ocena številčnosti medveda 2007. Univerza v Ljubljani, Biotehniška fakulteta, 79 str.

Støen OG, Zedrosser A, Saebo S, Swenson JE (2006) Inversely density-dependent natal dispersal in brown bears *Ursus arctos*. Oecologia 148, 356-364.

Swenson E. Jon, Gerstl Norbert, Dahle BjØrn, Zedrosser Andreas. 2000. Action Plan for the conservation of the Brown Bear (Ursus arctos) in Europe. Convention of the Conservation of European Wildlife and Natural Habitats (Bern Convention). Nature and environment, No.114. Council of Europe Publishing, 68 pages

Wooding B. John, Hardisky S. Thomas. 1994. Home range, habitat use, and mortality of black bears in North Central Florida. Bears: their Biology and Management, Vol. 9 (1): 349-356