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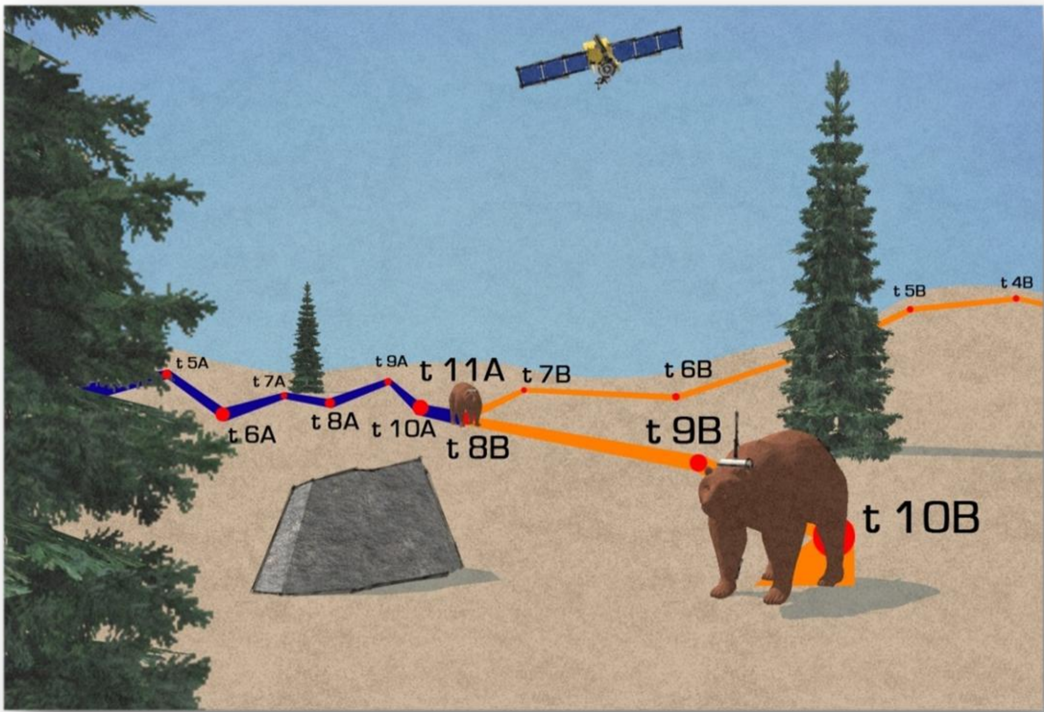
Spatio-temporal analysis of brown bear (*Ursus arctos*) interactions in the mating season

David Haberkorn



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Skandinaviska Björnprojektet

Spatio-temporal analysis of brown bear (*Ursus arctos*) interactions in the mating season

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Foreword

When colleagues first pointed out the thesis topic on the university website to me, the subject of this research was on GIS analysis of plant seed dispersal by brown bears. Throughout various meetings and discussions, the topic changed to analysis of interactions between brown bears and wolves and finally evolved to what is presented in this thesis. This report represents almost one year of work for obtaining my MSc in Geo-Information Science and Remote Sensing, including the development of a proposal for this research, doing fieldwork in the Swedish forests and realising the analysis. During this period, I had to go through a lot of problems in the implementation, costing both time and sometimes also motivation. On the other side there were rewarding moments too, when for example complex scripts and models started to work out and delivered meaningful results. The fieldwork in Sweden (although not directly connected to this thesis work) was a great period, not only due to the great Swedish landscapes, but also thanks to the wonderful people which were part of this experience. Summing up this thesis means a lot of new knowledge and skills that I obtained, both on research in general, but also on the technical side of implementation and of course on brown bears. I liked the work from the beginning to the end, and I am glad that the results of this research are meaningful and of use for further research.

Therefore, I want to thank everyone who made this thesis work possible and who supported me during the last months while working on it. In the first place, I want to thank my supervisor here at Wageningen University, Ron van Lammeren. He was always as excited about this thesis as I was and I went away from each meeting with him with new ideas and fresh energy. Without his positive attitude to this project, the whole process would have been a different one, his constructive ideas and guidance into the right directions was important for the thesis work. Without the great support of John Stuiver and Aldo Bergsma concerning analysis and programming, it would not have been possible for me to implement the methods as planned and to obtain results as present by the end of this research. Thanks to both for spending hours with unwilling ArcGIS functionalities and complex Python scripts. My gratitude goes also to Ignaz Heitkönig, who took the effort of reviewing the information leaflet for the expert validation before sending it to the experts. His feedback improved the quality of the leaflet, which led to better understanding through improved presentation of methods and results of this research. This immediately leads to all the experts from the Scandinavian Brown Bear Research Project, particularly to my supervisors Jon Swenson and Andreas Zedrosser, who agreed on taking part in the expert validation and therefore adding great value to this work. This not only justified the way I conducted my research, but also added extra value and issues to discuss to this thesis work. Furthermore, special thanks go to Jon for the extensive review of this report (thanks to an erupting volcano in Iceland), finally making my English sound good. Additional thanks go to Sam Steyaert, who made this thesis possible in first instance. I also want to thank the colleagues at the field station in Tackåsen, who made the time in the field a really enjoyable and unforgettable one. Special appreciations go to Sven Brunberg for bringing my old Toyota back to life and to Shane Frank, for simply having a damn good time with him.

Last but not least I want to thank my family, especially my parents and my aunt and uncle. Their hard working in order to be able to support me made studying at university possible for me in first instance. Thanks a lot for that and for never stopping to believe in me.

Wageningen, May 2011

Abstract

Little is known about the mating related behaviour of the brown bear, for example how individuals find or track down each other, how long they stay together or which bears associate with others in terms of reproductive status or sex. In order to better understand the ecology of the brown bear, the Scandinavian Brown Bear Research Project (SBBRP) uses GPS collars to record the movements of brown bears. I have used these GPS movement data for a spatio-temporal analysis. The objective was to analyse behavioural patterns in order to obtain new knowledge about the brown bear mating system. The first research question aimed at extracting an individual's reaction after crossing the track of another individual in terms of changes in speed and direction. In total, 672,118 intersections have been extracted from the datasets and presented regarding changes in speed and direction according to different ages of the crossed tracks (0 – 24 h, 24 h – 72 h, 72 h – 168 h, 168 h – 336 h, > 336 h) and different sex classes. The second research question concerned the extraction of encounters between individuals and determination of their duration. Encounters were defined as positions of two bears within a spatial threshold of either 100 m or 200 m and within a temporal window of ±15 minutes. In total, 628 encounters were extracted for a spatial threshold of 100 m and 793 for the 200 m threshold. They were presented according to different sex and reproductive status class combinations. The analysis was conducted by implementing the spatio-temporal concepts '*lagged co-incidence in space and time*' and '*co-incidence in space and time*' (Andrienko and Andrienko, 2007; Andrienko et al., 2008) in a ArcGIS 9.3 with Hawths Tools extension and custom programming in Python. The methods and results of this analysis were validated by experts from the SBBRP and are confirmed to be useful and delivering new knowledge about the mating related behaviour of the brown bear. The analysis developed during this research can also be applied to movement data of other species.

Keywords: spatio-temporal analysis | movement patterns | GPS trajectories | GIS | data mining | *Ursus arctos* | mating behaviour | animal interactions

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Abbreviations

API .... **Application Programming Interface**

DCB .... **Dynamic Collective Behaviour**

DOP .... **Dilution Of Precision**

ESRI .... **Environmental Systems Research Institute**

GIS .... **Geographic Information System**

GLM .... **Generalised Linear Models**

GLMM .... **Generalised Linear Mixed Model**

GME .... **Geospatial Modelling Environment**

GMT .... **Global Mean Time**

GNSS .... **Global Navigation Satellite Systems**

GPS .... **Global Positioning System**

IMB .... **Individual Movement Behaviour**

LMT .... **Local Mean Time**

MCB .... **Momentary Collective Behaviour**

MPO .... **Moving Point Object**

POI .... **Point Of Interest**

RT 90 .... **Rikets Koordinatsystem 1990**

SBBRP .... **Scandinavian Brown Bear Research Project**

SMS .... **Short Message Service**

SQL .... **Structured Query Language**

VHF .... **Very High Frequency**

WGS 84 .... **World Geodetic System 1984**

1 Introduction

This first chapter provides background information on the brown bear in Sweden as well as on animal tracking and spatio-temporal analysis in general. Furthermore, the objective and the research questions of this thesis are presented. The last subchapter provides an overview of this thesis report.

1.1 Context

Although the brown bear (*Ursus arctos*) "*became locally extinct across large parts of North America and Europe in the 19th and 20th century*" (Nellemann et al., 2007: 158), the populations in Scandinavia are currently expanding (Kindberg et al., 2011). About 95-98% of this Scandinavian population is found in Sweden (Swenson, 1995; Zedrosser et al., 2001), where it grew from approximately 130-300 individuals in 1930 to about 3,300 in 2008 (Swenson et al., 1998; Kindberg et al., 2011). Currently, the Scandinavian brown bear population is regarded as the most productive worldwide (Zedrosser et al., 2001; Nawaz et al., 2008), with an approximate growth rate of an estimated 4.5% per year (Kindberg et al., 2011).

Ursus arctos is a solitary carnivore with a promiscuous mating system (Schwartz et al., 2003 in Støen et al., 2005; Støen et al., 2006; Steyaert et al., 2011), but it may be more social than previously presumed (Støen et al., 2005). However, little is known about the mating related behaviour of the brown bear, for example how individuals find or track down each other, how long they stay together or which bears associate with others in terms of reproductive status or sex.

The Scandinavian Brown Bear Research Project (SBBRP) was founded in 1984 in order to understand the ecology of the brown bear and to provide a scientific basis for both management of the species and information to the public (SBBRP, 2010). The research is conducted in two study areas, one of them in the north of Sweden (Norbotten County) and a southern area in the counties of Dalarna and Gävleborg in Sweden and in Hedmark/Norway. In 2003, GPS monitoring (Global Positioning System) of bears began, adding new possibilities to the still used Very High Frequency (VHF) tracking for monitoring purposes. Since then, vast quantities of spatial data have been recorded. These data can be used for spatio-temporal analysis in a Geographic Information System (GIS), in order to better understand the (mating-related) behaviour of the Scandinavian brown bear.

1.2 Background

The use of telemetry to study animals started in the 1950s and 1960s (Mace and Waller, 1997; Hebblewhite and Haydon, 2010), using VHF beacons. The advent of global navigation satellite systems (GNSS), mainly GPS, brought both increased volume and precision regarding the obtained data into the field of wildlife studies, and therefore represents a powerful tool (Hebblewhite and Haydon, 2010).

Studies using telemetry data have been carried out focusing on different aspects like movement patterns and home ranges (McLoughlin et al., 1999; Amstrup et al., 2001; Parks et al., 2006), activity patterns (Matthews et al., 2006; Kolowski et al., 2007) or habitat use (Mace et al., 1999; Liu, 2001; Nellemann et al., 2007; Elfström et al., 2009). Among others, these analyses can be part of further studies like the interactions between animals and humans (Swenson et al., 1999), interspecies interactions (Rogers and Mech, 1981; Gunther and Smith, 2004) or intra-species interactions (Mace and Waller, 1997; Stenhouse et al., 2005). Studies on interactions between bears like from Mace et al. (1997) use for example home ranges and their overlaps to find out about interactions between individuals. They are based on datasets with coarse temporal resolutions (location detection frequency ≥ twice a week) and can therefore not precisely analyse direct interactions between individuals. In the study of Stenhouse et al. (2005), GPS tracking data (logging frequency up to 1 hour) is used, which enables more detailed analysis on interactions between individuals.

As improvement in GPS tracking technology regarding battery life or storage capacity allows collection of continuous positioning data nowadays, also more sophisticated analysis is possible. The analysis however does not only depend on the data available, but also on analysis methods, especially regarding low level/high level events (see '2 Spatio-temporal analysis and concepts'). Although GPS data from tracked entities (persons, vehicles, or in this case – animals), is present in abundance ("*The travel behaviour researcher faces GPS data like a child faces a candy store – there is so much there, that it is difficult to get started.*", Axhausen et al., 2004: 3), the methods for analysis and representations on the other hand seem to be far more scarce (Peuquet, 2001; Dodge et al., 2008). Gudmundsson et al. (2007) state, that there is a lack of analytical concepts for the increasing amount of movement data. Andrienko and Andrienko (2007) point out, that there is need of finding adequate methods for analysing this kind of data and extracting relevant information. Peuquet (2001: 12) even compares spatio-temporal representation with "…*encountering a strange creature in the dark and then having it pose a series of riddles.*", referring to the creature 'Gollum' in Tolkiens fiction novel *The Hobbit*. However, there are analysis methods and concepts available for analysis of movement data, or to be more precise, trajectories or geospatial lifelines (Laube et al., 2005b; Andrienko et al., 2008). This research is designed to find out, whether (selected) concepts and methods are applicable on GPS tracking data provided by the SBBRP in order to extract information regarding brown bear interactions. Although studies on brown bear behaviour and interactions have been conducted before, none were carried out in this field so far using high frequency GPS tracking data as provided by the SBBRP, applying concepts mentioned above, so as to extract high level spatio-temporal phenomena indicating behavioural patterns.

1.3 Objective

The aim of this thesis is to find out whether spatio-temporal concepts are applicable to animal tracking data, especially for analysing brown bear interactions during the mating season, so as to obtain new information about the brown bear mating system.

1.4 Research questions

In order to fulfil the objective of this explorative study, it has to be broken down into its components. First of all, research on available spatio-temporal concepts has to be carried out and suitable concepts have to be chosen. This refers to the first two research questions. After those have been answered, the two main research questions can be addressed. Finally, the methods and results of the analysis have to be validated, leading to the last research question.

- What spatio-temporal concepts are available?
- Which concepts can be applied in order to extract behavioural information?
    - Can changes in speed and direction be detected after an individual crosses the track of another individual? (referred to as research question 1/RQ 1 from now on)
    - Can encounters between individuals be extracted and how long do they last? (referred to as research question 2/RQ 2 from now on)
- Are the methods and results of the spatio-temporal analysis valid and useful regarding mating season related behaviour?

1.5 Guidance

Chapter '2 Spatio-temporal analysis and concepts' gives an introduction to spatio-temporal analysis and the concepts that are available. It moreover presents the concepts selected for this research. The following chapter '3 Bear tracking data' contains an introduction to the study area, a description of the bear tracking data available and delineates on the pre-processing of the data. The methodology applied, as well as elaborate explanations of the analysis can be found in chapter '4 Methodology'. The next part '5 Spatio-temporal patterns – results' describes the results that have been obtained from the analysis. Chapter '6 Expert validation' presents the results of the validation of the methodology and results conducted by the experts from the SBBRP. The final chapter '7 Discussion, recommendations and conclusion' comes up with conclusions, discussion and recommendations.

2 Spatio-temporal analysis and concepts

This chapter provides an introduction on spatio-temporal analysis and gives examples of application. Furthermore, a selection of concepts that are available for analysis in regard to spatio-temporal data mining is given. Finally, I present and explain the concepts I selected in order to answer the research questions.

2.1 Spatio-temporal analysis

Geographical data is dynamic in its nature on many temporal scales. The scale can be large, like the movement of continents over the ages, or on a smaller scale like an object such as a rally car moving on a special stage, where time is measured in milliseconds instead of millions of years. Both examples do have one thing in common though: spatial attributes change over time. In order to investigate these changes, special methods which can handle information both on space *and* time are required. This is where spatio-temporal analysis comes in.

Although the matter of spatio-temporal analysis is quite young (Peuquet, 2001), it is applied in a wide palette of scientific and professional applications. It is utilised for research on spread of diseases (Kao et al., 2008; Wen et al., 2011), dispersion of pests (Koch and Smith, 2008), species abundance (Denis et al., 2002) and even for detection of e-mail spam or vandalism on Wikipedia in form of offensive edits (West et al., 2010), just to name a few. Another field of research is the analysis of movement data, also called spatio-temporal data mining (Amstrup et al., 2001; Axhausen et al., 2004; Laube et al., 2005a; Laube et al., 2005b; Stenhouse et al., 2005; Parks et al., 2006; Andersson et al., 2007; 2008; Andrienko et al., 2008; Benkert et al., 2008; Gonzalez et al., 2008; Gudmundsson et al., 2008; Ligtenberg et al., 2008; Giannotti et al., 2009), where spatio-temporal analysis is applied on different studies. The basis for such analysis are trajectories, showing paths of entities through space, which require a certain amount of time for these movements (Andrienko et al., 2008). Such can be analysis of movements of people (e.g. football players in Laube et al., 2005a; visitors in nature areas in Ligtenberg et al., 2008; human movements in Gonzalez et al., 2008) or on data obtained from tracked vehicles (Axhausen et al., 2004; Andrienko et al., 2007; Giannotti et al., 2009). However, spatio-temporal analysis has been used to a lesser extent in animal studies (Stenhouse et al., 2005). Data and information obtained from tracked pedestrians or cars have some features in common, which they do not necessarily share with animal movements. One such a characteristic is, for instance, a restricted spatial extent in terms of predefined paths/fixed routes and constrained space, where the entities are able to move. This means that pedestrians or hikers are (theoretically) limited to movements on pavements or trails, land-based vehicles can only move on existing networks like roads and not on waterways (of course there may be exceptions like a tractor moving on a field or meadow). Animals on the other hand are not limited to this kind of infrastructure (although they may use it), which means that they will move freely in the terrain; they may even use both water and land for their movements, depending on the species.

Another difference can be the importance of landmarks or points of interest (POI), regarding the tracking of pedestrians or vehicles and the stops of movement that are connected to them. By analysing stops at these locations, the researcher can learn about behaviour of the tracked entities, as these stops may be related to certain activities (e.g. work, shopping, (un-) loading of freight, etc.). Furthermore, landmarks can influence the travelling behaviour of entities. These POIs and landmarks may be of less interest in animal tracking (although they may exist, e.g. settlements, agricultural fields, bait stations, feed-lots, etc.), as landmarks may not be used by animals in terms of navigation for example. The temporal aspect of stops, however, may indicate the activity of an animal (e.g. foraging, sleeping, hibernation, etc.).

2.2 Spatio-temporal concepts

These differences already indicate that spatio-temporal analysis concerning movement data is not primarily designed for animal behaviour analysis. However, there are concepts concerning movement data and -patterns that are based on generic approaches. Such concepts can be applied on the data provided by the SBBRP in order to extract specific information, so the research questions regarding animal behaviour can be answered. There is a range of different concepts according to literature. Some are more basic and some more sophisticated and on higher levels. These different levels nevertheless, do not reflect the quality of the concepts, as more complex ones are derived from base/low level concepts in most cases.

The most basic concepts are those regarding positions in space and time – *location* and *time*. Information on where (X, Y, Z) and when (date, time) positions are recorded, is the basis for all following concepts. Such can be *distance* between consecutive positions, *time lag* between consecutive positions, the *speed* with which a distance has been covered or the *direction* of the movement. The concepts of *change* or *similarity* (which are not necessarily bound to spatio-temporal analysis), indicate alterations or resemblances in attributes like speed or direction between certain locations or instants in time (Andrienko et al., 2008). When analysing trajectories of different entities however, more advanced concepts are required in addition. Such can be *co-incidence in space and time*, *co-location in space* or *lagged co-incidence* (Andrienko and Andrienko, 2007; Andrienko et al., 2008; Dodge et al., 2008), which can be extracted from such trajectories. Other patterns are *clustering* , *flock patterns*, *periodic patterns*, *meeting places/encounters*, *frequent locations/convergence* or *leadership* (Laube et al., 2005b; Andersson et al., 2007; Gudmundsson et al., 2007; Andersson et al., 2008; Benkert et al., 2008; Gudmundsson et al., 2008).

2.3 Which spatio temporal concepts can be applied

In order to find and analyse interactions between individuals during the mating season in movement datasets according to the research questions, several of the mentioned spatio-temporal concepts may be applied on the data provided by the SBBRP. For answering the research questions, they first of all have to be analysed regarding the concepts on which they are based.

2.3.1 RQ 1

For answering this question, the crossings between tracks of different individuals have to be found. Such an intersection can be defined as an individual passing a location where another individual has already been. This definition accords to the concept of *lagged co-incidence in space and time* (Andrienko and Andrienko, 2007; Andrienko et al., 2008; Dodge et al., 2008). After an intersection has been found, *speed* and *direction* can be compared to before and after the crossing. This conforms to the concept of *change* (difference) in certain attributes between two instances in time (Andrienko and Andrienko, 2007; Andrienko et al., 2008; Dodge et al., 2008). This concept relates to the behaviour of one individual (after it crosses the track of another individual), which is referred as ‘individual movement behaviour‘ (IMB) (Andrienko and Andrienko, 2007; Dodge et al., 2008) in spatio-temporal analysis.

2.3.2 RQ 2

This research question is aimed at finding encounters between two individuals. An encounter is defined here as two individuals having the same positions in both space and time. As exactly equal positions will not occur in reality, positions within thresholds, both in space and time, will be considered to be an encounter. This matches with the concept of *co-incidence in space and time* as described in Andrienko et al. (2008); Andrienko and Andrienko (2007) and Dodge et al. (2008). This concept relates to two or more individuals that are involved in an encounter. When encounters only occur at a given instance (e.g. two individuals meet but do not stay together) this refers to ‘momentary collective behaviour‘ (MCB), if they stay together over a certain period of time this is called ‘dynamic collective behaviour‘ (DCB) (Andrienko and Andrienko, 2007; Dodge et al., 2008).

Figure 2.1 shows both of the selected spatio-temporal concepts in a graphic representation. On the left-hand side two moving point objects (MPO) are displayed, whereas identical positions in space and time can be observed for both MPOs (an encounter). On the right-hand side however, positions of two individuals are the same in space, but not in time. This example shows one MPO using the same path as another one (e.g. one individual tracking another one), an equal position nevertheless could also be an intersection between two trajectories.

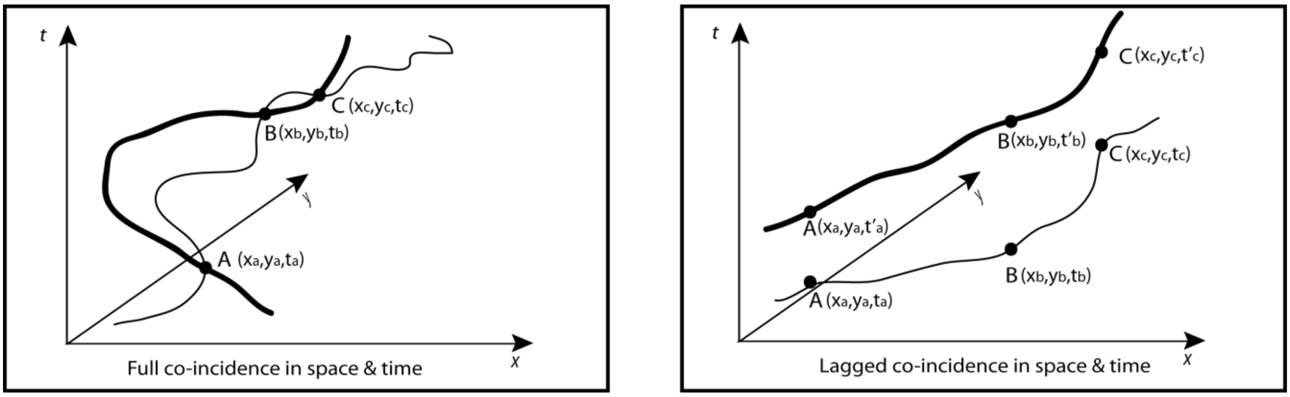


Figure 2.1 Full- and lagged co-incidence in space and time (source: Movement Pattern Wiki, 2011).

2.4 Conclusion

The main concepts selected for this research as defined by Andrienko et al. (2008) and Andrienko and Andrienko (2007) are shown below as summary:

- **Change** (difference): behaviour changes from moment t1 to t2 (speed, direction)
- **Lagged co-incidence in space and time**: position of individual A is the same as of individual B, but at a different time (intersections)
- **Co-incidence in space and time** (full co-incidence): positions are same in space and time (encounters)

These concepts have been selected, as they represent simple and logic approaches to the complex matter of spatio-temporal analysis for this research. Furthermore, they suit the requirements for the analysis so as to answer the research questions. However, these concepts are based on more basic ones. Table 2.1 shows an overview of all the concepts that are applied in this research (also apart from the ones mentioned above). They are classified into three levels of events and according to their spatial and/or temporal dimension. This scheme was adapted and slightly modified from Dodge et al. (2008) for this research. The low-level events compare to primitive parameters whereas mid- and high-level events are primary and secondary derivatives from the latter ones. Low-level events represent the basic information that a recorded position offers – positions in both space and time. Mid-level events are derived from these basic ones and show the direction of a movement, the time lag between the recorded positions (logging frequency) and the speed with which distances have been covered. At the high-level, the lower ones come together to show behavioural patterns like change in direction/speed or encounters between different individuals and their durations.

Table 2.1 Concepts classified into three levels of events. (adapted from Dodge et al., 2008).

	low-level	mid-level	high-level
spatial	position in space	direction	change of direction spatial proximity (thresholds)
temporal	position in time	time lag between two positions	temporal proximity (thresholds) duration of encounter
spatio-temporal	change in position (includes change in time)	speed	intersections: tracks with different ages cross each other (lagged co-incidence) encounters: spatial and temporal proximity (thresholds; full co-incidence) change in speed

3 Bear tracking data

This chapter provides background on the study area were the data for this analysis was obtained. Next, information on the tracking data itself is presented, explaining in what form it is provided by the SBBRP and the attributes it contains. The variables which are required for this analysis are described as well as the complete pre-processing of the data.

3.1 Study area

The study area is located in the counties of Dalarna and Gävleborg in south-central Sweden and in Hedmark in south-eastern Norway (61°N, 15°E, Figure 3.1) and covers a total area of about 29,000 km² (this number is derived from the extent of all brown bear positions from 2006 to 2009). It is the southern of two study areas where research is conducted by the SBBRP. There is a rolling landscape with elevations ranging from 200 m in the south-eastern part to about 1,000 m in the western part at the Norwegian border (Dahle and Swenson, 2003b). Large parts of the study area are covered by lakes and bogs, but the main land cover is highly managed productive boreal forest (about 80%). The dominating tree species are Scots pine (*Pinus sylvestris*) or Norway spruce (*Picea abies*), but also Lodgepole pine (*Pinus contorta*), birches (*Betula* spp.) and European aspen (*Populus tremula*) are present in the study area (Moe et al., 2007). An extensive road network consisting of minor gravel logging roads and paved public roads with more traffic can be found throughout the whole area, as well as various town and settlement areas which vary in size from 500 to 11,000 inhabitants (Nellemann et al., 2007; Wikipedia, 2011). Bears have been abundant in the area for more than 30 years (Nellemann et al., 2007), the population has a density of about 30 bears per 1,000km² (Støen et al., 2006 in Zedrosser et al., 2007). Although the population is hunted, the numbers are stable, though at the western, eastern and southern boundaries of the study area the population is even expanding (Kindberg et al., 2011).

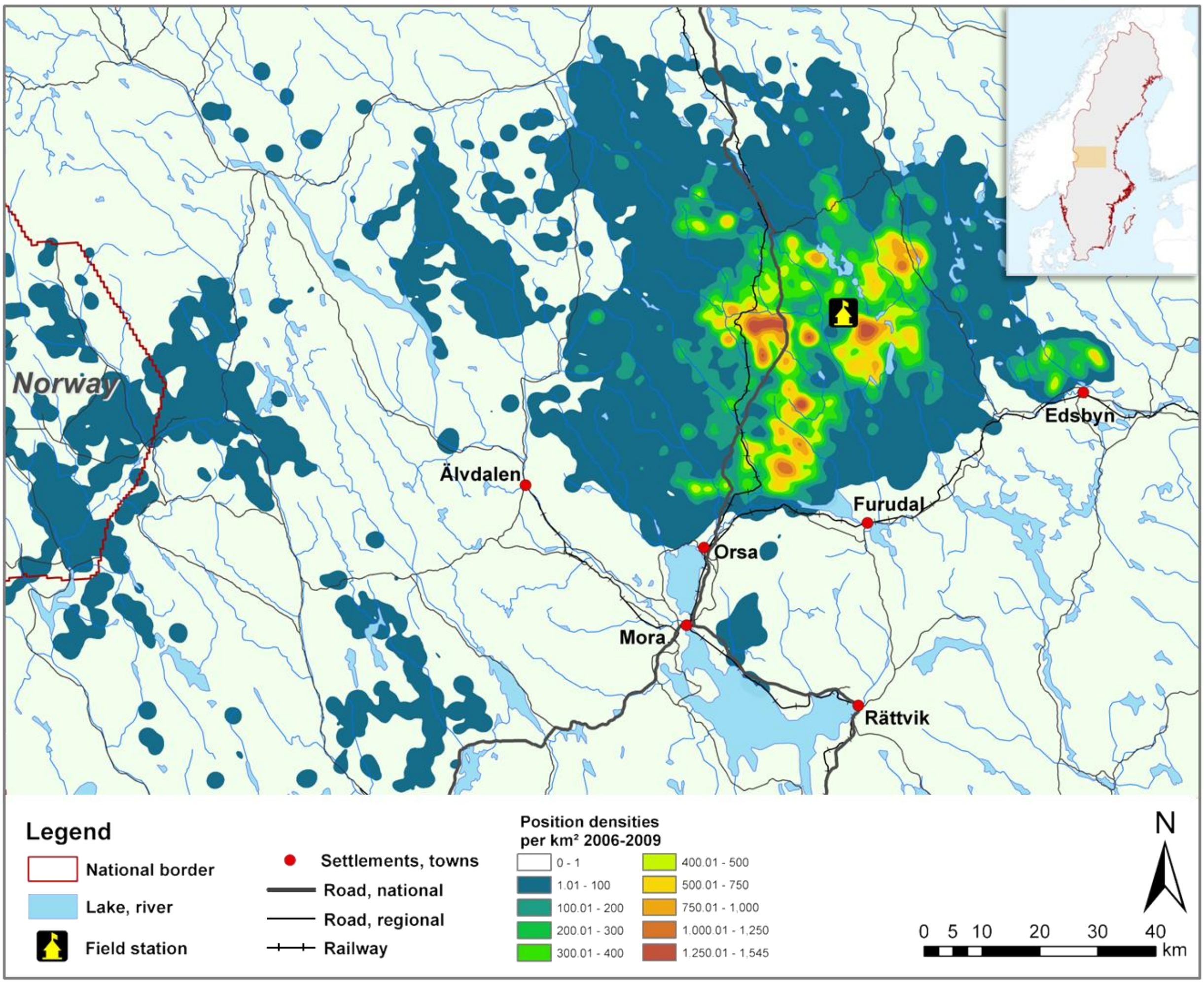


Figure 3.1 Study area and brown bear positions density per km² for the years 2006-2009 (Kernel Density).

3.2 Bear data

Currently, the SBBRP tracks 111 brown bears (Brunberg, 2010) in the two study areas (status 2010). This is performed by using Vectronic Aerospace GPS PLUS collars (Vectronic Aerospace GmbH, 2010) (Figure 3.2, Figure 3.3), in order to gain better understanding of how brown bears behave and interact. The data obtained not only shows positions in space of individuals in their habitat, but also contains information about movement patterns, which express spatio-temporal behaviours (Gudmundsson et al., 2007). The high logging frequency (compared to other wildlife studies) of the GPS collars (positions are usually logged every 10 or 30 minutes, respectively; up to under 1 minute [according to observations in data] in certain cases) makes this data quite unique in the field of (not only) brown bear studies and also offers a new perspective of possible research. Furthermore, the spatial accuracy of the collars is indicated with 10-15 m, whereas the mean deviation is below 3 m for validated 3D fixes (recorded positions) (Schulte, 2011). Experience from fieldwork, where denning sites of bears were located, confirmed this high spatial accuracy of the collars. Due to this fine temporal and spatial resolution, an analysis on direct interactions between individuals and how they approach each other can be conducted, given that suitable analysis methods are available and applicable.

Figure 3.2 Bear with collar (source: Vectronic Aerospace GmbH, 2010)

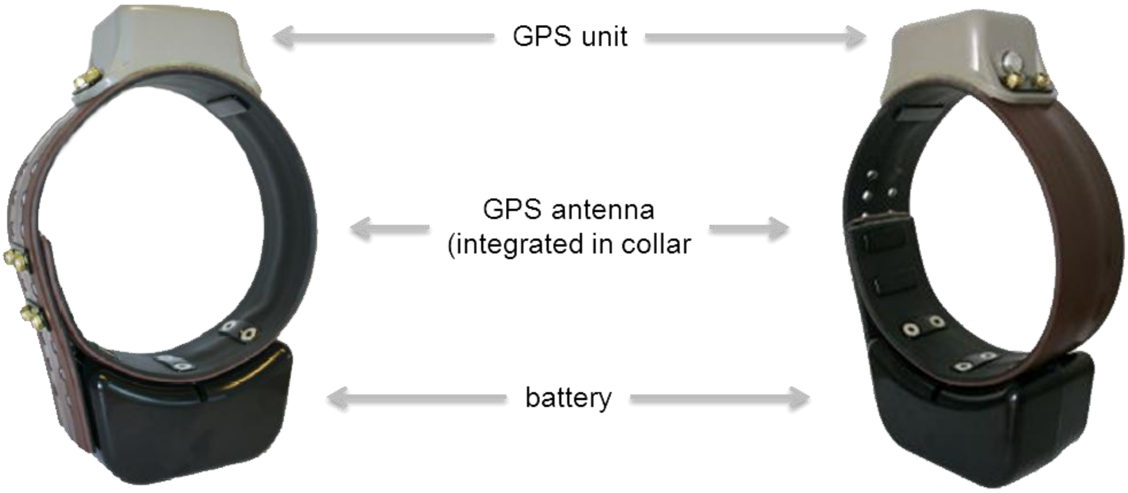
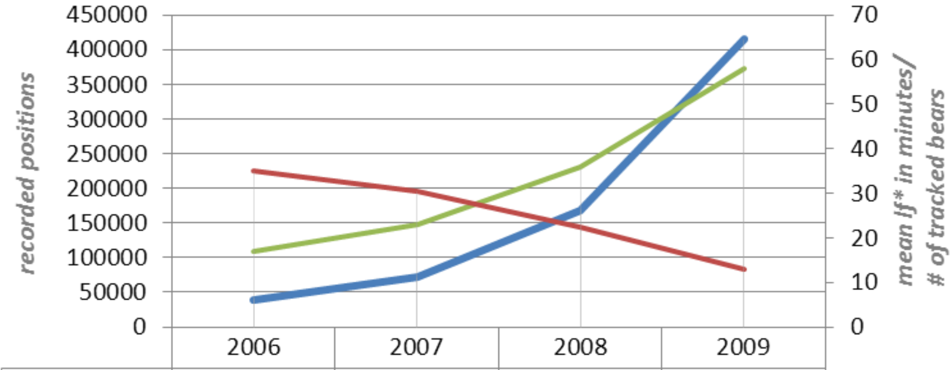


Figure 3.3 Vectronic Aerospace GPS PLUS collar (source: Vectronic Aerospace GmbH, 2010)

The number of individual brown bears that are tracked by the SBBRP is increasing every year (Figure 3.4, Figure 3.5). The data available for this research includes the years 2006-2009, whereas the amount of recorded positions increases (almost) exponential compared to the amount of tracked bears. As the collars log positions 24 hours a day every day, in combination with the high logging frequencies the amount of recorded positions becomes massive. The usual logging interval is either 10 or 30 minutes, as mentioned before, but sometimes logging intervals are larger due to changed schedules or technical reasons (e.g. position cannot be taken due to poor reception, etc.). However, mean logging frequencies for the data used in this study decreased from 34.9 minutes for the 2006 dataset to 12.8 minutes in the 2009 dataset, which also explains the exponential increase of data volume. This means (as data volumes are big), that, in order to reduce computing time and to ensure most efficient processing, the pre-processing of this data is important.



	2006	2007	2008	2009
positions	39025	71560	168143	414400
bears	17	23	36	58
mean lf*	34.9	30.3	22.5	12.8

*mean lf = mean logging frequency

Figure 3.4 Increase of GPS positions during the mating seasons in relation to number of tracked brown bears and mean logging intervals in the study area in Sweden and Norway. The scale on the left shows the number of recorded brown bear positions per year (blue graph), the scale on the right shows number of bears (green graph) and logging intervals in minutes respectively (red graph).

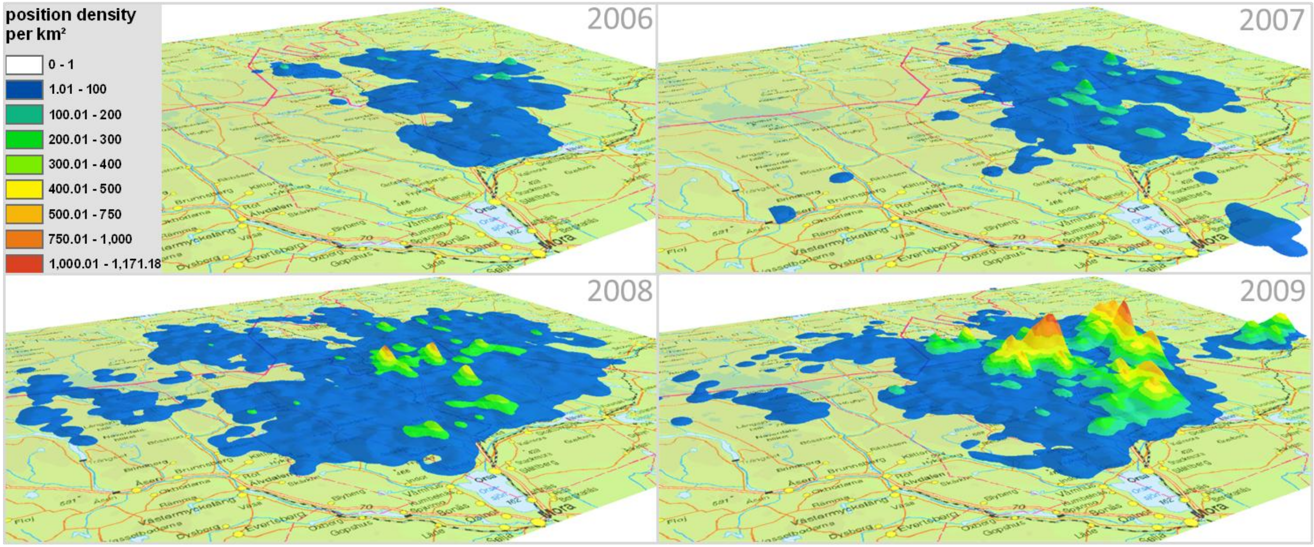


Figure 3.5 Densities of recorded brown bear locations and spatial extent in the study area in Sweden and Norway from mating seasons 2006 to 2009.

3.3 Input datasets, variables, procedure- and results of pre-processing

In order to allow a processing that is as efficient as possible regarding further data handling and analysis, the available data have to be prepared in several pre-processing steps. Not only has the data to be imported into a GIS, also additional variables and demographic information have to be added, which have to be prepared as well.

3.3.1 Source datasets

The GPS tracking data, from now on referred to as 'position data', are provided in a database, which basically contains three tables (positions 2006, 2007, and 2008/2009 combined) (Figure 3.6, left). These tables contain not only GPS positions of tracked bears from January to December, but also various additional attributes which are recorded by the GPS collars (collar ID, ID and name of tracked individual, GMT/LMT date and time, coordinates and height values in WGS84 and RT90, DOP (Dilution Of Precision), type of navigation (2D, 3D), number of satellites used, temperature, date of SMS (when data is transferred to server), etc.). In total there are 1,672,148 positions (76,892 for 2006, 163,821 for 2007, 345,898 for 2008 and 1,085,537 for 2009) available for analysis (Figure 3.1).

Data regarding demographic information on the bears however, is not included in this data. These data are contained in two additional files (Seggregationbears.xlsx, Tidsaxel 100818.xls) (Figure 3.6, right). These tables include attribute data like reproductive status (RS) per month, sex, year of birth or weight, even though this information is not available for all bears/months. These demographic data were be joined to the spatial data during the pre-processing.

As the volume of the data is quite big, not all attributes were be kept (as they would not be used), only required demographic data were joined to the spatial data for analysis.

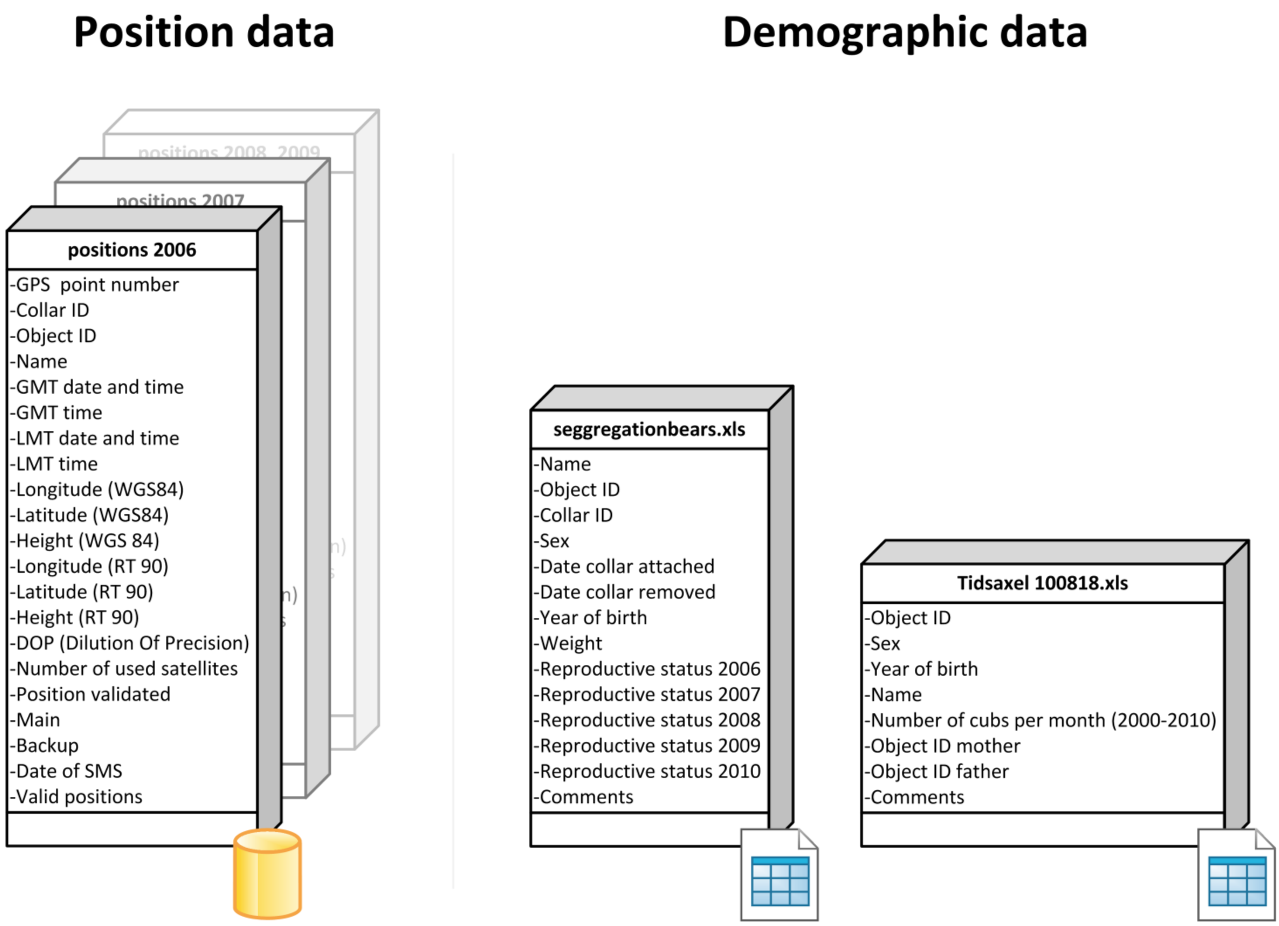


Figure 3.6 Input tables and their attributes (position data stored as tables in database) for radio-collared brown bears in Sweden and Norway.

3.3.2 Variables

Several spatial and temporal variables are required for the spatio-temporal analysis. Some of them, like coordinates of positions or time stamps (time and date, when positions were recorded) are already present in the base data (position, position time; Figure 3.7 *a* and *e*), some are created during the pre-processing (step, bearing, turnangle and netdisp; Figure 3.7 *b-d)* and others are calculated during the various processing steps (step time, speed; Figure 3.7 *f* and *g*).

- **position:** X, Y and Z coordinates of recorded position (Z not required for this analysis)
- **step:** the distance between the current (p) and the next (p+1) position[1]
- **bearing:** the bearing of the step between current position (p) and the next position (p+1); 0° - 360°[2]
- **turn angle:** the absolute value of the angle between the previous and the next step (angle between points p-1, p, p+1); change in bearing; from -180° to +180°[3]; change in direction
- **netdisp:** the distance between the first and the current position[4] (not required for this analysis)
- **position time:** local date and time when position was recorded (LMT (Local Mean Time); GMT (Global Mean Time) also available, but not applied)
- **step time:** the duration of a step (time p+1 – time p); this is also logging frequency/interval
- **speed:** the velocity with which and individual was moving between two consecutive positions

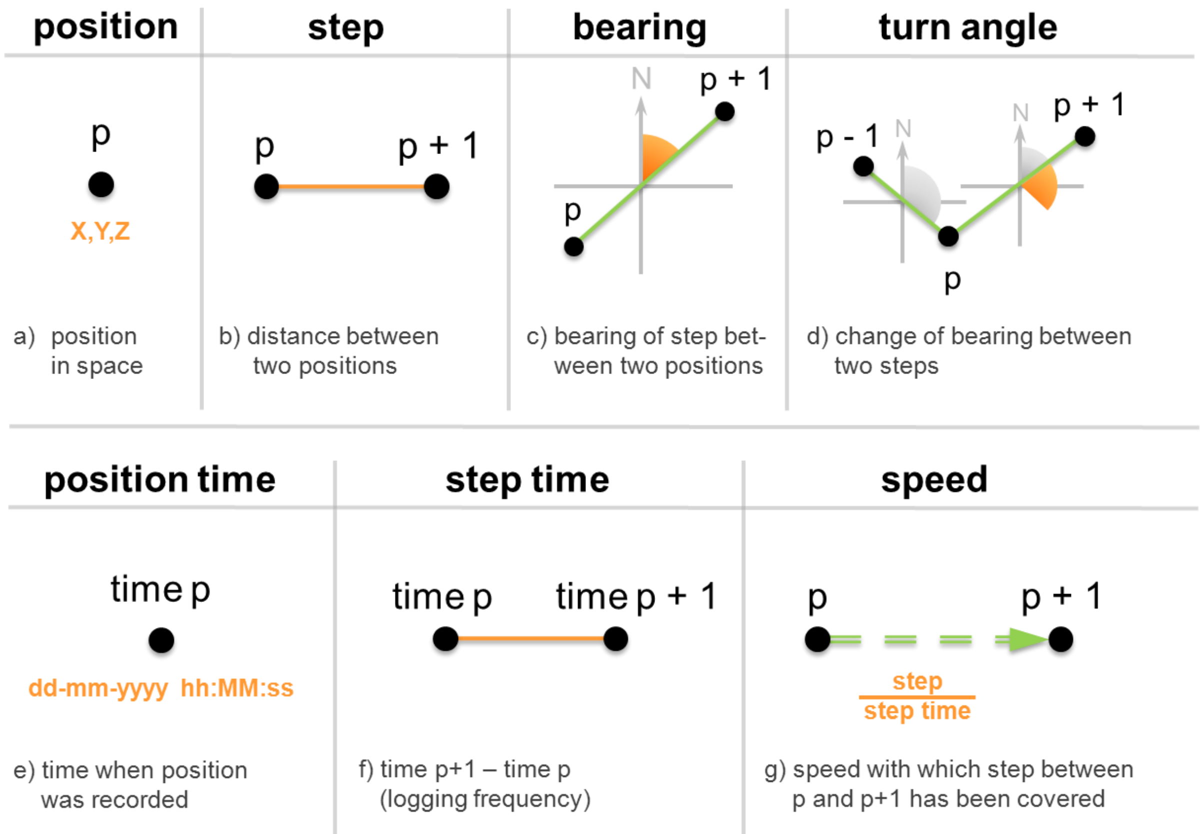


Figure 3.7 Spatial (a-c), temporal (e-f) and spatio-temporal (d, g) variables used in this study.

The total spatial extent for this study is the study area, although also each individual has its own spatial extent, the so-called home range (McLoughlin et al., 1999; Amstrup et al., 2001; Parks et al., 2006). The temporal extent is the mating season May – mid July (Dahle and Swenson, 2003b), for the years 2006 -2009.

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1 Spatial Ecology, 2010
2 Spatial Ecology, 2010
3 Spatial Ecology, 2010
4 Spatial Ecology, 2010

3.3.3 Pre-processing

An overview of the pre-processing is presented in Figure 3.8,which shows all steps that are described as follows. The first pre-processing step was to import the position data into ArcGIS via the 'Add XY Data' tool. All spatial data were imported and handled in the projected Swedish national grid 'RT90 2.5 gon West' coordinate system during the whole project. After the position data had been successfully imported, they were stored/exported as shapefile or as feature (which is the preferable option) for further use.[5] [6]

In a next step, the data falling within the mating season (May – mid July; Dahle and Swenson, 2003b; Støen et al., 2006) were extracted. The earlier described movement parameters 'Steplength' (step), 'Turnangle', 'Bearing' and 'Netdisp' were calculated on basis of this dataset with the help of Hawths Tools (Spatial Ecology, 2010) in the next phase.

Subsequently, the demographic data were prepared for joining to the position data. Therefore, a table (final_demographic.xlsx) was created, which contained information compiled out of the earlier mentioned files (Seggregationbears.xlsx, Tidsaxel 100818.xls). This table contains the following attributes:

- Unique ID of the individual (e.g. W0425)
- Name of the individual (not necessarily required for analysis)
- Sex
- Year of birth[7]
- Weight[8]
- Reproductive status for each month of the mating season (May, June, July) for each year (2006-2009)[9]

The field containing the unique ID was used in the next step to join the demographic information to the right individual. The field 'reproductive status' could take the following values:

-	bear not born yet
D	dead bear (indicating it died during the mating season)
SAM	sub adult male (age < 5 years)[10]
SAF	sub adult female (age < 5 years, no litter yet)
AM	adult male
RF	reproductive female (can be younger than 5 years if she had litter before)
COY (x)	female with cubs of the year (number of cubs)
YL (x)	female with yearlings (number of yearlings)

After the demographic data was prepared, it could be joined to the position dataset in ArcGIS. Due to exporting problems, several manual steps (creating and re-calculating fields) were required. For reasons of data reduction, information on reproductive status was limited to only one entry per position (reproductive status according to current year and month).

[5] Note that this description always talks about the processing steps *per year*. All processes have to be executed for each year.
[6] The whole pre-processing is also schematically depicted in Figure 3.8.
[7] Note that this information is not available for each individual, as not all records in the base datasets are complete.
[8] Note that this information is not available for each individual, as not all records in the base datasets are complete.
[9] Note that this information is not available for each individual, as not all records in the base datasets are complete.
[10] Sub adults are classified as bears (both male and female) younger than 5 years (Swenson et al., 1997; Swenson et al., 2001, Zedrosser et al., 2007).

As a next step, the dataset containing all positions from all bears for the mating season was split up in order to obtain a single dataset per individual. This could either be done by creating selections for each individual, by using the Hawths Tools function 'Split Vector Layer By Unique Value Field' or by batching a selection via a script (which is the preferable option).

The following processing step contains the conversion from the point datasets into line datasets via a Python script. This script does not use ArcGIS functionality and works efficient and fast (e.g. same process in ArcGIS for 2009 dataset 90+ hours instead of approximately 2 hours!). After calculating the speed of the movements in a further script, in a final step the single line datasets were merged again into one dataset per year. This step concluded the pre-processing.

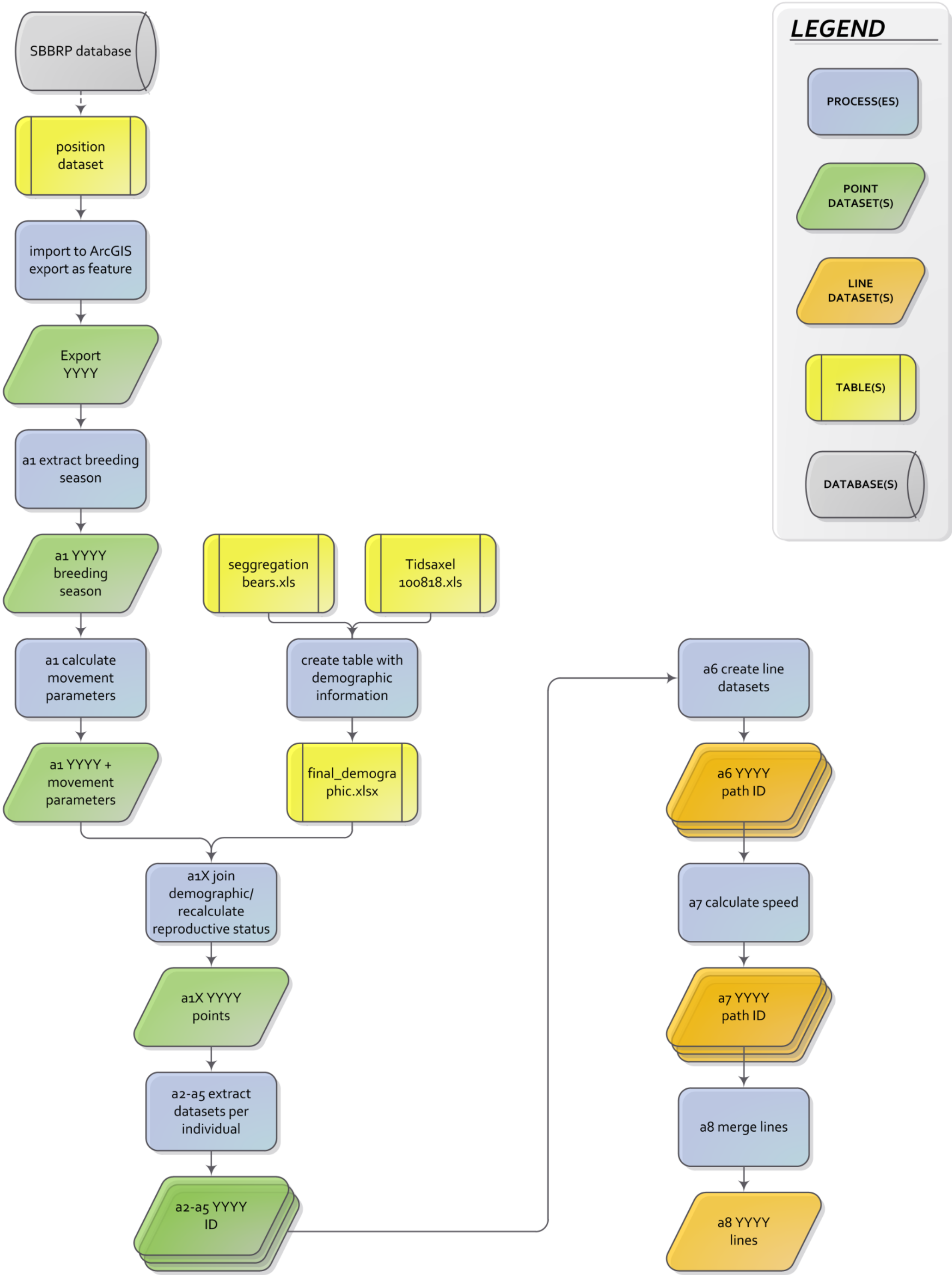


Figure 3.8 Schematic representation of pre-processing of the brown bear GPS data.

3.3.4 Results

As a result, basically four types of datasets per year were created and enriched with additional information regarding demography and movement parameters (Figure 3.9, Figure 3.10). Processing step 'a1X' produced a dataset with all bear positions per year; 'a2' to 'a5' are the point datasets per individual derived from the 'a1X'-datasets (a2 for 2006, a3 for 2007, etc.). Datasets 'a7' are line datasets for each individual, which are the basis for the 'a8' dataset, a line dataset including all individuals.

Figure 3.9 Result datasets after pre-processing (green objects indicate point datasets, orange ones line datasets; 'YYYY' stands for the year, 'ID' for the object ID of the individual).

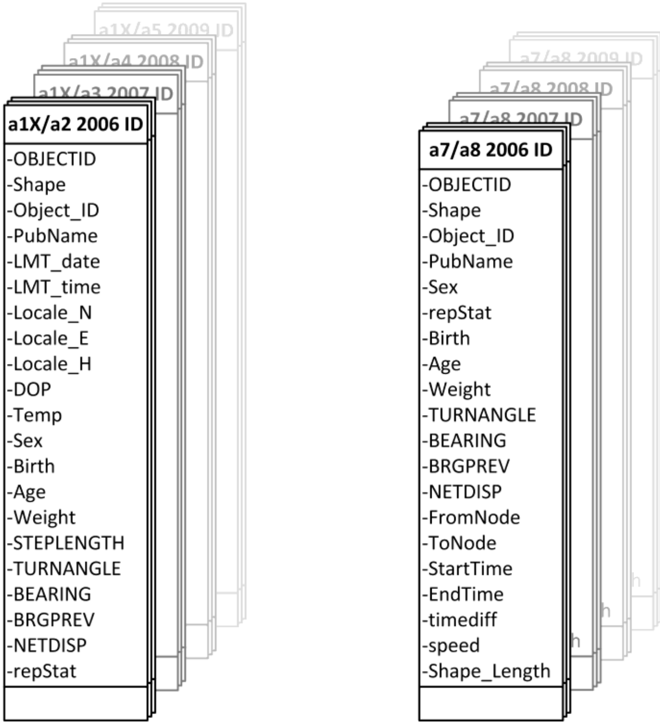


Figure 3.10 Attributes of pre-processing output datasets (left – point-, right – line datasets).

3.4 Conclusion

The preparation of the data is essential for further processing and analysis steps. Since the amount of positions can be immense (compare e.g. 2009 dataset), it is important to take into account issues like for example size of new fields (e.g. does it have to be of type 'long', or is 'short' sufficient; limit length of text fields – e.g. 20 instead of 255, etc.). Regarding this kind of optimisation, it is also worth considering excluding the demographic data from the spatial data and joining it to the results at the end of the analysis. As (especially during the pre-processing at the begin of the project) a lot of learning and trial-and-error was included, there is room for improvement not only regarding the pre-processing, but also concerning data quality itself, as not all (demographic) attributes are complete in the base data.

4 Methodology

This chapter gives an overview about how this research concerning the two main research questions was conducted. After a general introduction, the analysis steps for each research question are presented, showing how results were obtained. This is done by giving a step-by-step description of the processing steps as they were implemented.

4.1 Methodological framework

The methodology of this research is mainly based on the GIS implementation of the spatio-temporal concepts that I found to be applicable, in order to answer the research questions. The analysis is basically divided in four main parts as illustrated in Figure 4.1, which depicts the basic workflow of the analysis framework. It presents a strongly simplified scheme showing the main steps and concepts regarding the GIS analysis. First of all, the raw data provided by the SBBRP has to be pre-processed (compare '3.3.3 Pre-processing'). Following this step, the methodology splits up into two parts. The first part concerns the first research question. Crossings (intersections) of trajectories have to be extracted (lagged co-incidence). After that, analysis regarding how the crossing individual reacts in terms of changes in speed or direction can be conducted. This has to be done using different temporal ranges, which represent the age of the crossed tracks. The results can be presented according to sex class combinations or other attributes, and how individuals react after crossing another individual's path. The second part deals with research question 2. The basis are encounters between two individuals, which means that positions which are equal in space and time (co-incidence in time and space) have to be extracted. As identical positions (regarding space and time) do not (or hardly) occur in reality, spatial and temporal thresholds/buffers will be used. After these positions have been found, durations of encounters can be calculated. The exact methods, models and algorithms are to be developed during the implementation phase. The delivered results of this methodology, as well as the applied methods, are validated through experts from the SBBRP in the end. Therefore, an information leaflet presenting the methods, results and questions regarding this research, will be created in order to offer the basis for the expert validation.

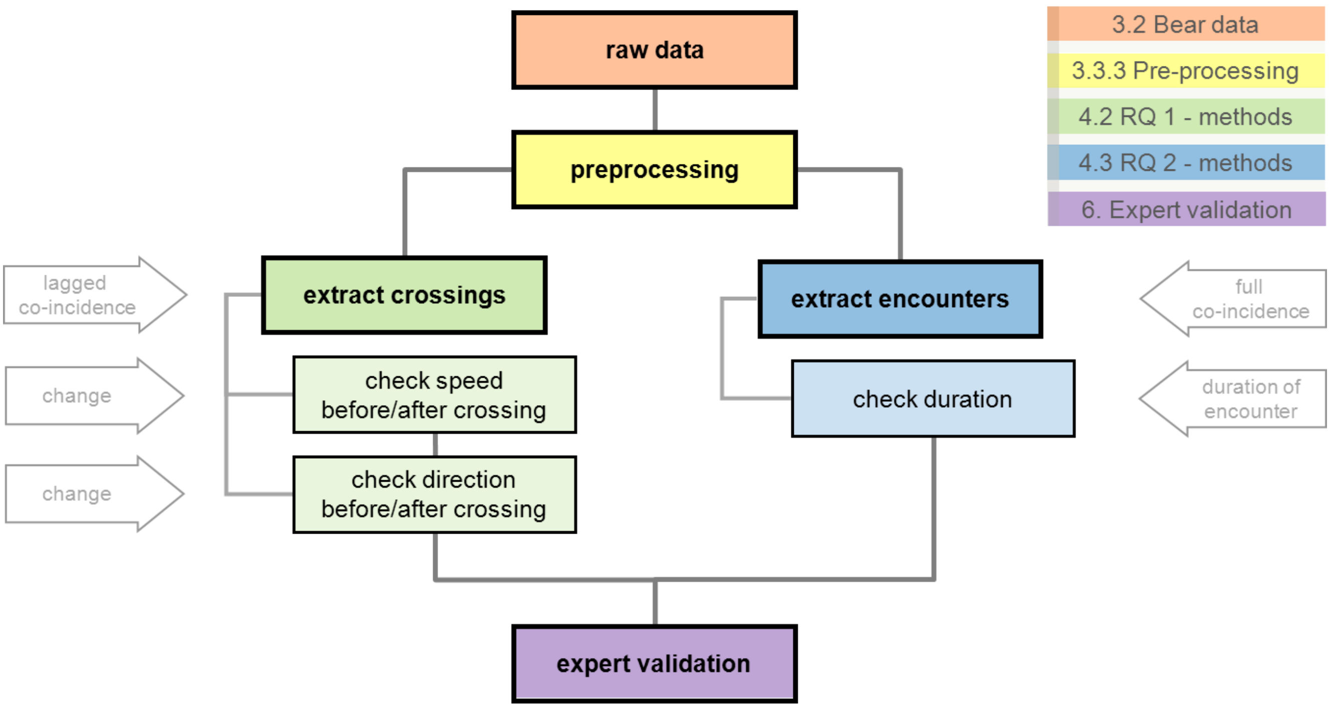


Figure 4.1 Schematic representation of processes and spatio-temporal concepts in methodological framework.

Although software tools especially designed for spatio-temporal analysis are available (e.g. CommonGIS for visual analysis, (Andrienko et al., 2004); visualization tools like in Bertolotto et al. (2007); for an overview refer to Andrienko et al., 2003), conventional GIS software will be used during this research. The implementation of the spatio-temporal concepts required for the analysis was conducted with the help of the software package ESRI ArcGIS 9.3.1 (Build 4000) (ESRI, 2010) with additional extensions Hawths Tools 3.27 or Geospatial Modelling Environment 0.4.0 (GME; Spatial Ecology, 2010). Due to limitations of these standard packages (e.g. regarding handling of big datasets, batch processing, etc.), customization via an external application programming interface (API) like Python (Python, 2011) is required. All the mentioned have also already been applied during the pre-processing steps.

The results of this methodology represent patterns that can be found in behaviour. They can be analysed according to different attributes of the individuals, which are obtained by the demographic data, in a successive ecological and statistical analysis (not part of this thesis). An advantage of this methodology is that it not only provides the possibility for analysis of brown bear movements during the mating season. It can also be applied for other species/moving objects, other attribute queries, different temporal ranges or interactions between different species. As there is already one wolf pack establishing in one of the study areas (the female is equipped with a GPS collar), this methodology can be a tool for studying for example wolf-bear interactions in future.

4.2 RQ 1 - methods

This research question is based on intersections (*lagged co-incidence in space and time*) of tracks, as they show individuals crossing the tracks of other individuals (Figure 4.2). The basic idea is to find steps like S2, which intersect with trajectories of other individuals and to compare their values regarding speed and bearing to the step before (S1). Speed will also be compared between step S1 and S3.

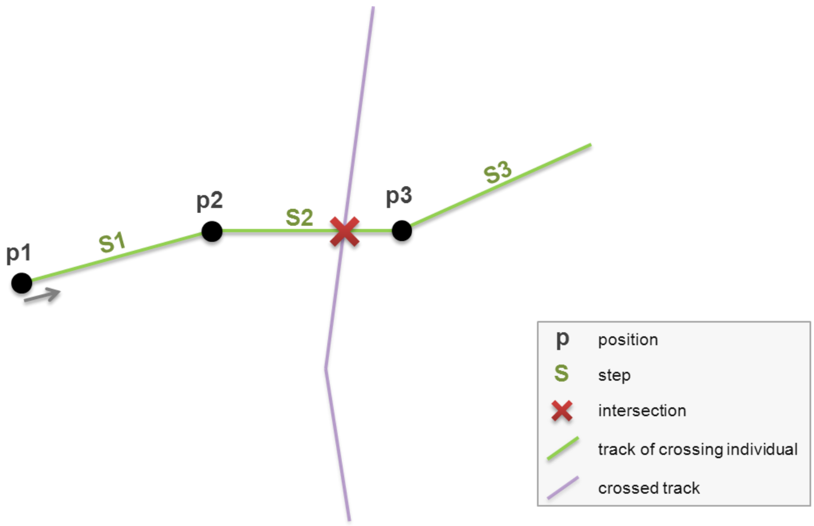


Figure 4.2 Basic concept for analysis on research question 1.

Therefore, I had to create intersection datasets for each individual. This means that each individual line dataset created during the pre-processing (a7_YYYY_path_W0004, a7_YYYY_path_W0010, etc.) had to be intersected with each other line dataset of the particular year, which was done by the scripts 'IAb1BSintersectionsLines' and 'IAb2PHcreateMissingIntersectsForIAb5'; see 'Processes research question 1'. These created intersection datasets (point datasets) for each combination of intersecting individuals. Basically, the first script already produced all intersections that occurred in that specific year, but it did not deliver a dataset for each individual. If for example bear 'W0004' and bear 'W0010' crossed their tracks as their habitats overlapped, then a dataset 'b1_intersects_YYYY_W0004_W0010' would be produced. As in further processing steps, a dataset for *each* individual was required, the second script produced the dataset 'b2_intersects_YYYY_W0010_W0004', although it also may contain redundant data. Empty intersection datasets created (as an individual does not cross paths of all other individuals) would be detected by the scripts and instantly deleted.

In the next step the intersection datasets were merged per individual ('IAb3BSmergeIntersectsPer-Individual').

Afterwards, information regarding the speed of the individual before and after the intersection was added. This was done by joining the datasets based on the attributes 'FromNode' and 'ToNode', which were created in step

‘IAa6PHScreateLines’. This means that each intersection record obtained information from the previous and the next step from the original datasets.

The next step simply merged all intersection datasets for the particular year into one dataset, as from now on all operations did not require individual datasets (‘IAb5mergeIntersects’).

Subsequently, I calculated the differences in speed between the step *before* the intersection and the step *at* the intersection and also between the step *before* and *after* the intersection, in order to obtain the change in velocity before and after the crossing. This was not done for bearings, as the field ‘TURNANGLE’ had already been created in the process ‘IAa1PHHTCalculateMovementParameters’, which indicated the absolute change in direction between the previous and the next step. Furthermore, the calculation of this value was too complex to implement, as the value of the bearing only goes from 0° to 360°, and the value for change in direction (‘TURNANGLE’) from -180° to +180° respectively.

After this calculation, the data processing was finished. The following two processes only created selections based on the total dataset (Table 4.1). Note that also more selections including the reproductive status (instead of sex combinations) are possible, although this would indeed create a lot of datasets for analysis. Moreover, additional specific selections either regarding different time scales (e.g. crossings within 12h, etc.) or concerning different combinations of reproductive status (e.g. when and adult male crosses the track of a reproductive female, etc.) can be carried out if desired. For more efficient selections (e.g. regarding reproductive status combinations) however, a query tool would be recommendable. The datasets resulting from these two processes can be used for interpretation in a further step (see ‘5.1 RQ 1 – results‘). A scheme of the whole processing for this research question is presented in Figure 4.3

Table 4.1 Final selection processes regarding age of crossed path and sex combinations.

Process	Selection criteria	Description
IAb7selectTemporalPeriods	0-24 h 24-72 h 72-168 h 168-336 h >336 h	These selections concern the age of the crossed track. They serve as a basis for further (ecological) analysis, e.g. how long can a bear still recognize the path of another bear, etc.
IAb8selectSexRelationsOfIntersects	M-M M-F F-F F-M	These selections concern the type of crossing regarding the sex of the individuals. Four possible combinations (2 classes) are available, although for further analysis also reproductive status can be used as a selection criterion (6 classes).

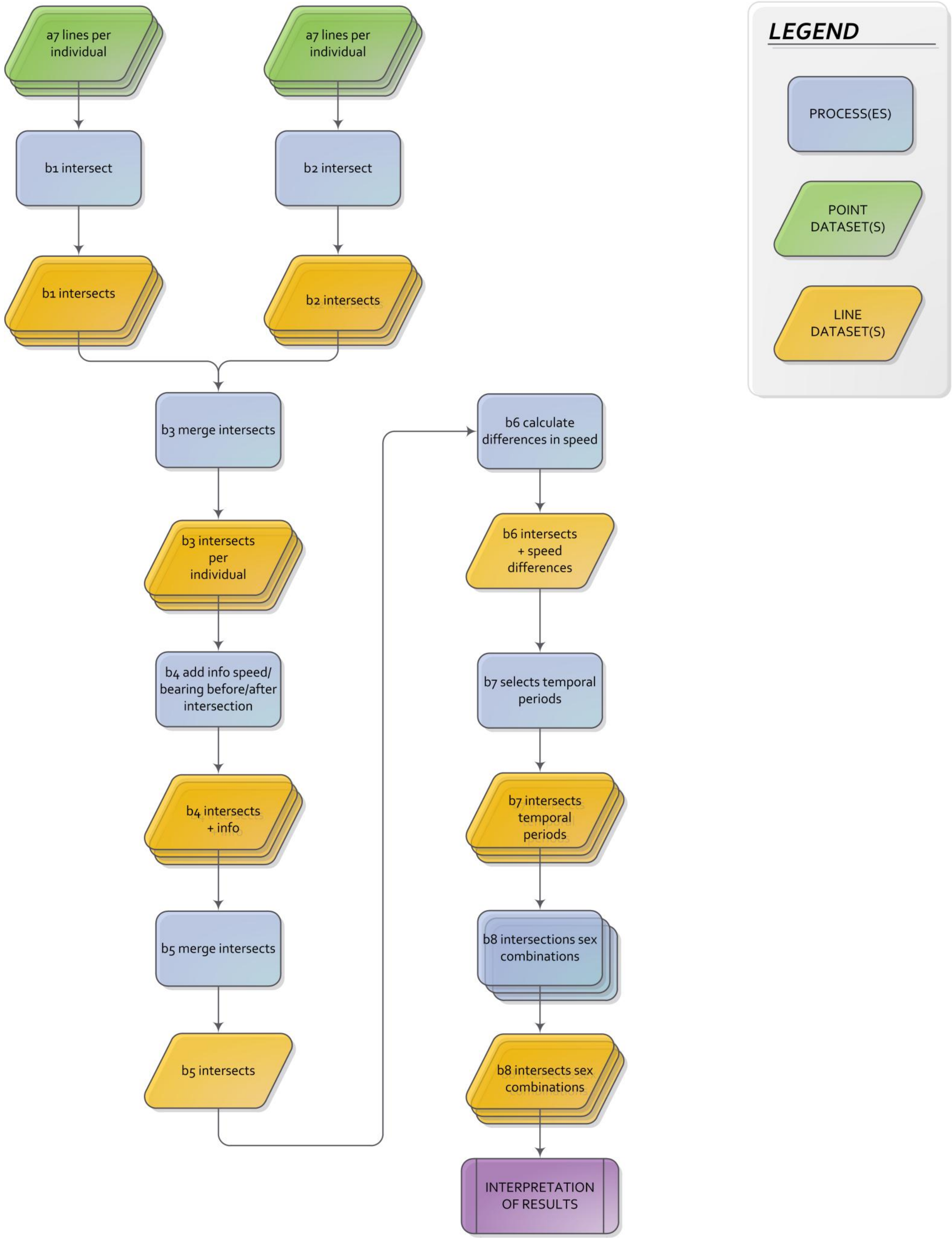


Figure 4.3 Schematic representation of processing for RQ 1.

4.3 RQ 2 - methods

This research question is based on the concept '*Co-incidence in space and time'* (full co-incidence). The underlying idea is to look at the positions for each individual and extract positions of the other individuals that are within spatial and temporal thresholds (relating to positions that are 'equal' in space and time). Figure 4.4 shows such positions for individual 1 as an example. It can be observed that positions of individual '2' and '3' are within the defined spatial threshold of individual '1', but only positions of individual '3' are also within the temporal threshold (e.g. ±15 minutes). This indicates that individuals '1' and '3' have actually met in this example (their positions coincide in space and time), but individual '1' and '2' have not.

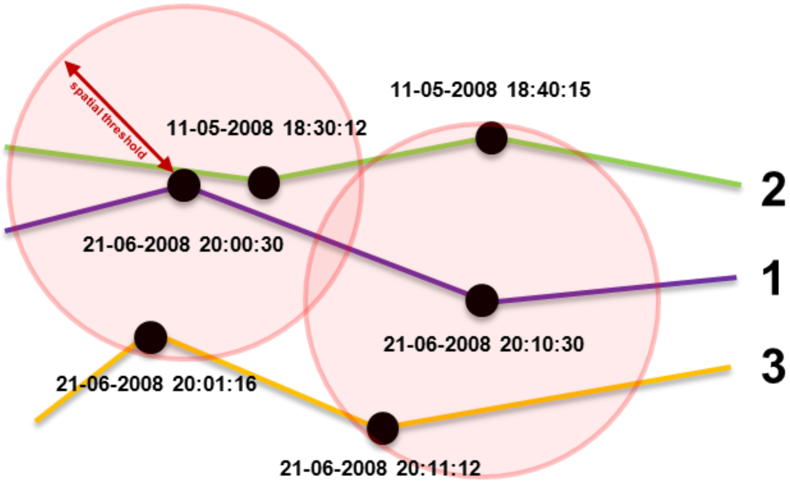


Figure 4.4 Basic concept for analysis on research question 2.

This means that positions that are within a defined spatial and temporal distance from other positions have to be extracted. As positions with exactly equal values in time and space are not realistic, both spatial and temporal 'buff-ers' or thresholds were used. Stenhouse et al. (2005) considered that two bears were aware of each other's presence within a distance of 500 m. As the spatial and temporal resolutions of the data used in this research were on a finer scale, the spatial and temporal thresholds which define a direct encounter were kept rather small. This means that positions within a spatial distance of 100 meters and 200 meters, respectively, and within a temporal distance of ±15 minutes were considered to be an encounter. The two different spatial distances were applied in order to evaluate what influence this would have on the end results.

The source data for this research question were the point datasets produced in the pre-processing steps a2 – a5 (per year). As initial steps, the time/date field were converted from the initial format (dd-mm-yyyy hh:MM:ss) to hours, to make the temporal calculations simpler in succession. The following step was the 'core' process of this analysis part. In this step, I extracted the positions within the defined spatial and temporal frame/buffer. An initial version of this step contained the ArcGIS tool 'Spatial Join', which turned out not to be suitable to the data, due to tool re-strictions (maximum number of join-records per record is 1,024 in one-to-many mode, join records within distance). Figure 4.5 shows an extract of the dataset 'a3_2007_W0231' (orange dots) which shows clustered positions (1,056) within the spatial threshold. The tool 'Spatial Join' was not able to join the information to the two positions of the dataset 'a3_2007_W0410' (green dots), as the number of positions exceeded the maximum capacity of 1,024. Even though not all of these positions were used in the end (as they were be within the spatial distance of 100 m/200 m, but not within the temporal frame of ±15 minutes), this step was necessary in order to obtain results.

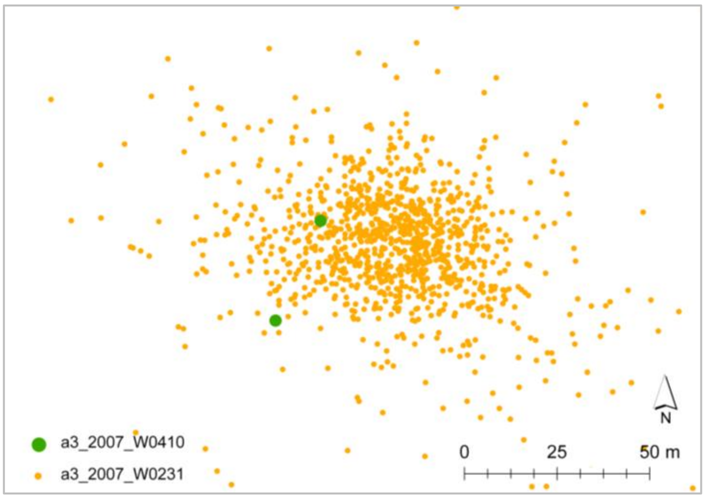
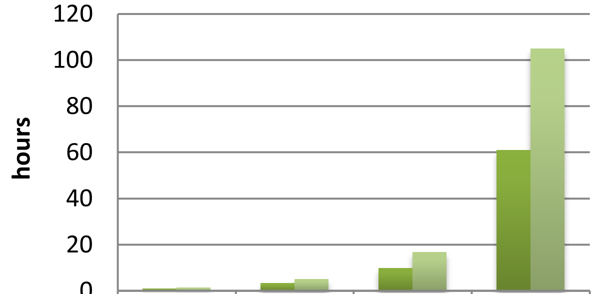


Figure 4.5 Dense spatial clustering of brown bear positions in a dataset.

Therefore this processing step required custom programming (scripts 'c2_select_encounters_YYYY_XXXm-_V2.py', see 'Processes research question 2'). This script manually calculated the distances from each position to all other positions. In series, it made use of ArcGIS functionalities in order to find and extract encounters according to the spatial and temporal criteria. As the selection of positions within certain spatial and temporal buffers of other positions is complex, the processing times can go up to 100+ hours (Figure 4.6). A more efficient algorithm or tool probably could save processing time for these massive datasets.



	2006	2007	2008	2009
processing time 100m	0.99	3.31	9.88	60.82
processing time 200m	1.39	5.06	16.8	104.87

Figure 4.6 Processing times for 'c2' scripts.

The script has to be executed twice for each year, in order to extract encounters for the two thresholds; 100 m and 200 m. The result tables were merged in the next step ('IAc3mergeEncountersPerYear'). The model 'IAc4addTimeDiff' calculated the time differences between the individual encounter positions, which were required later to define coherent encounters. As these time differences can contain 'NULL' values, they were transformed to the values '99999' in the next model ('IAc5changeNULLvaluesTimeDiffMinutes'). The subsequent script ('c6_YYYY_extractCoherentEncountersXXX.py') extracted coherent encounters. A coherent encounter is a pair of positions of two individuals, or a series of pairs of positions of two individuals, where the time difference between successive positions within the spatial and temporal distance may not be bigger than a certain threshold (in this case 5 hours). This value is not to be confounded with the temporal threshold mentioned earlier (±15 minutes). It ensured that, on the one hand, the absence of recorded positions was compensated, because due to e.g. technical problems positions may be missing. On the other hand, this threshold ensured that different encounters were separated. If the temporal lag between two pairs was bigger than this threshold, it was assumed that no encounters occurred during this period.

If all of the conditions were fulfilled, a unique value ('unique_encounterID') was assigned. This script had to be run twice for each year, as the unique values also depended on the two different spatial parameters (100 m/200 m). In the next model ('IAc7durationOfEncounters'), I calculated the duration of encounters, by subtracting the time of the first encounter position from the last one (as there may be more encounter positions between the first and the last position). Encounters with only one position will have a duration of 0, which indicated that two individuals met, but they did not stay together. The following models ('IAc8…' to 'IAc12…') prepared the results for the final analysis in terms of different tables for sex- or reproductive status combinations and calculating statistics. A scheme of the whole processing for this research question is presented in Figure 4.7.

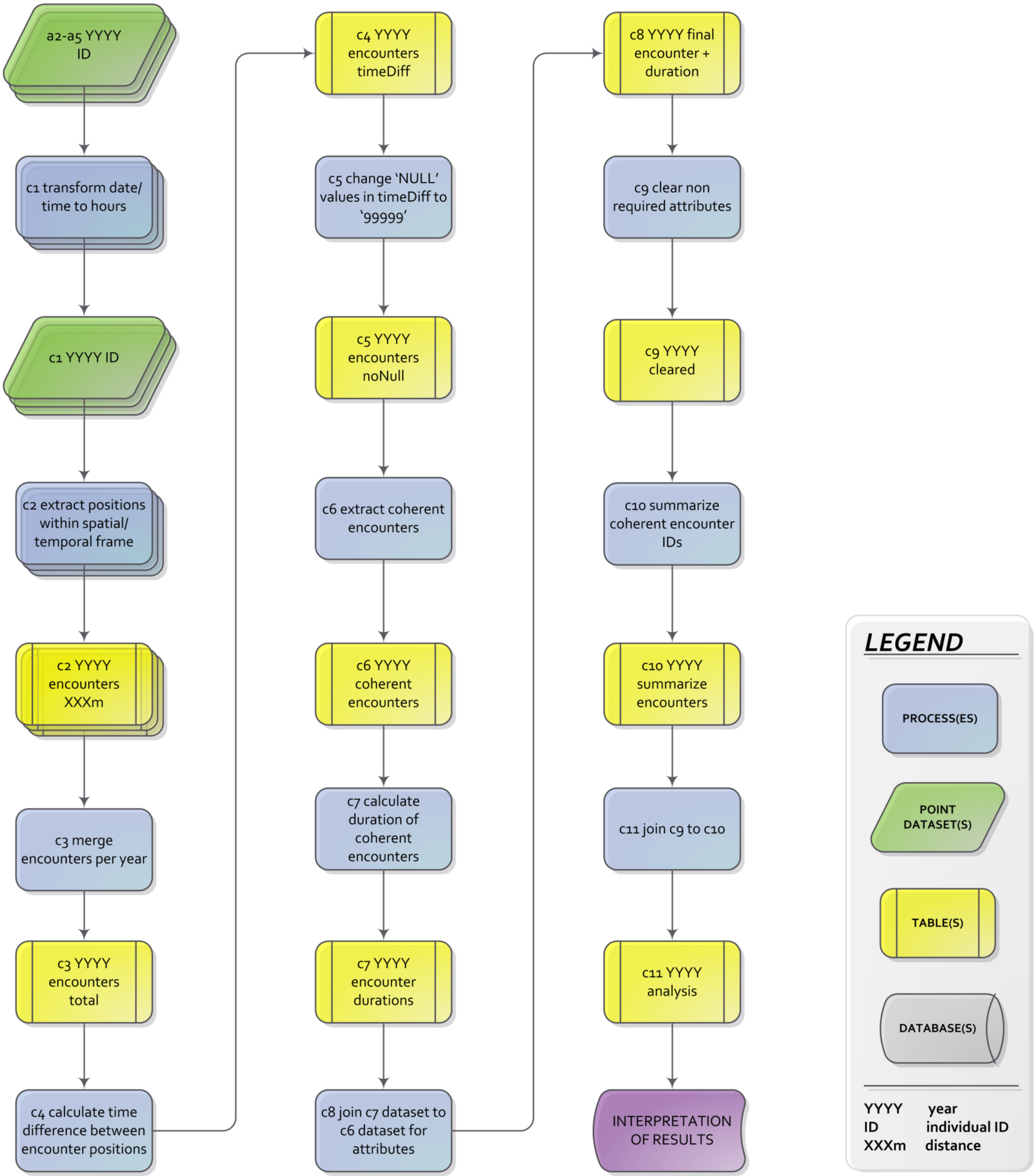


Figure 4.7 Schematic representation of processing for RQ 2.

4.4 Conclusion

Both parts of the analysis were successfully implemented and delivered results regarding the research questions. Nevertheless, as in the pre-processing step, there may still be room for improvement in various processing steps. As the aim of this research was to show whether an analysis of the provided data was possible concerning the research questions, this fact may play a minor part at this point. The methodology delivered results for both research questions, which are described in the next chapter.

5 Spatio-temporal patterns – results

This chapter describes the results obtained from the GIS analysis of this thesis work and the information leaflet, which was designed for expert validation. The extracted information will not be interpreted within this thesis, but will be validated and further analysed by experts from the SBBRP, as they have the ecological knowledge to interpret the results.

5.1 RQ 1 – results

The results of this analysis represented the change in speed and direction (turn angle) after intersections. In total, 672,118 intersections have been extracted from the datasets and examined regarding behavioural patterns (Figure 5.1). The outputs of the GIS analysis were delivered in the form of tables, which showed the changes in speed and direction according to sex- and reproductive status combinations per year. Further tables showed selections of these intersections according to how old the crossed track was (compare Table 4.1). All these 'averaged' values were derived from the individual intersects, which showed the behaviour for *each* individual bear and each individual intersection with a track that another bear had made (this was a spatial dataset). This means, that the results contained very detailed information for each individual, as well as overall behavioural patterns according to sex or reproductive status classes, possibly even indicating brown bear behaviour in general.

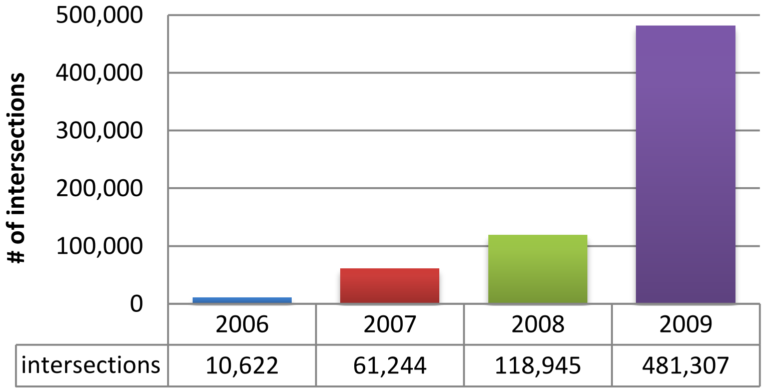


Figure 5.1 Total number of analysed intersections between individual brown bears per year on the study area in Sweden and Norway.

Figure 5.2 shows a scheme of the resulting output tables. All tables were based on a (spatial) dataset which contained all intersections that had been found. It was the basis for further selection according to sex and reproductive status combinations/classifications. The temporal selections for different reproductive status combinations were not created, as this would have resulted in large amounts of output tables (one per possible combination). Nonetheless, also this information can be extracted if required. Queries in a database would be preferable to produce all these results tables, but a database implementation was out of the scope of this thesis. Figure 5.3 shows examples of how the results have been prepared in form of graphs. Each graph contains averaged information on change of direction or speed per sex-class combination and per year. Furthermore, sample sizes and standard deviations are provided.

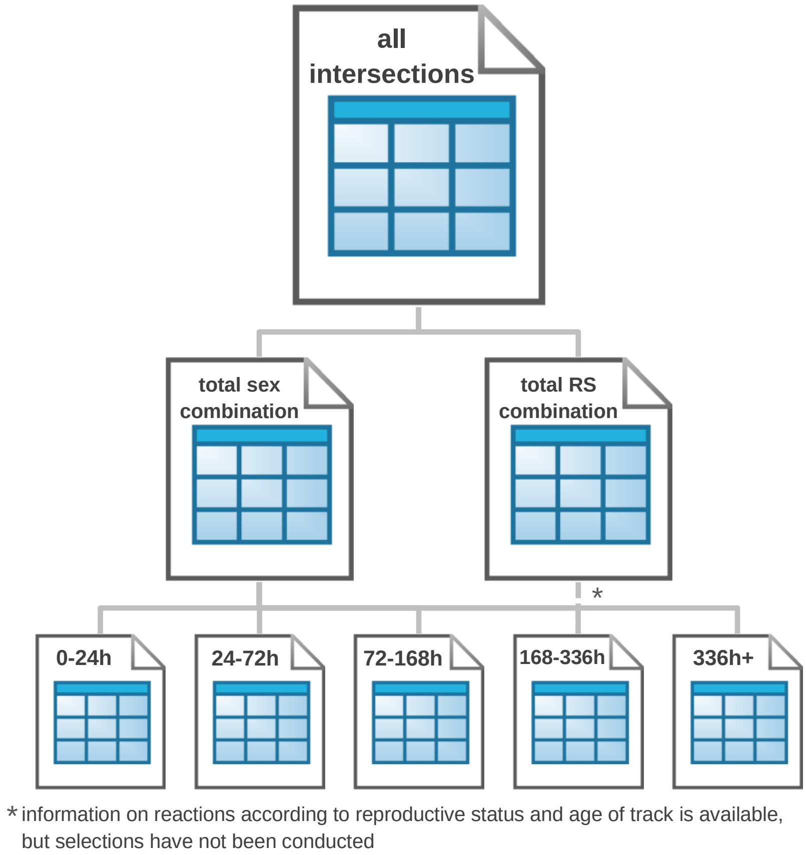


Figure 5.2 Schematic overview of produced output tables (per year).

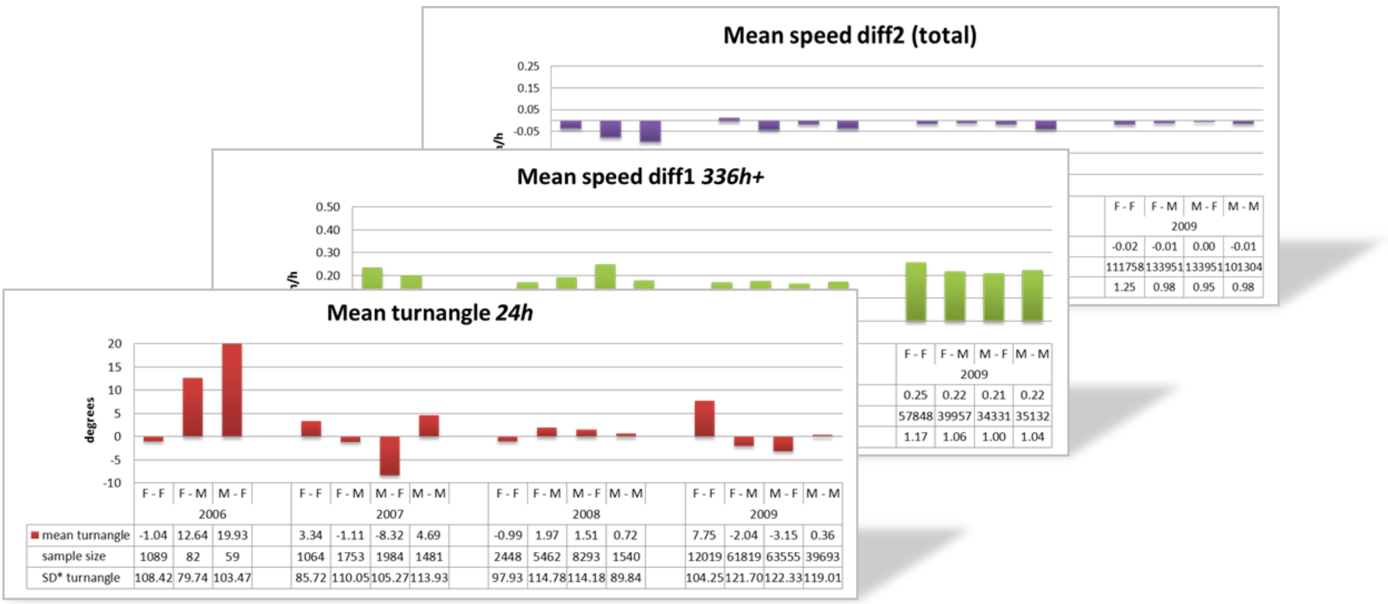
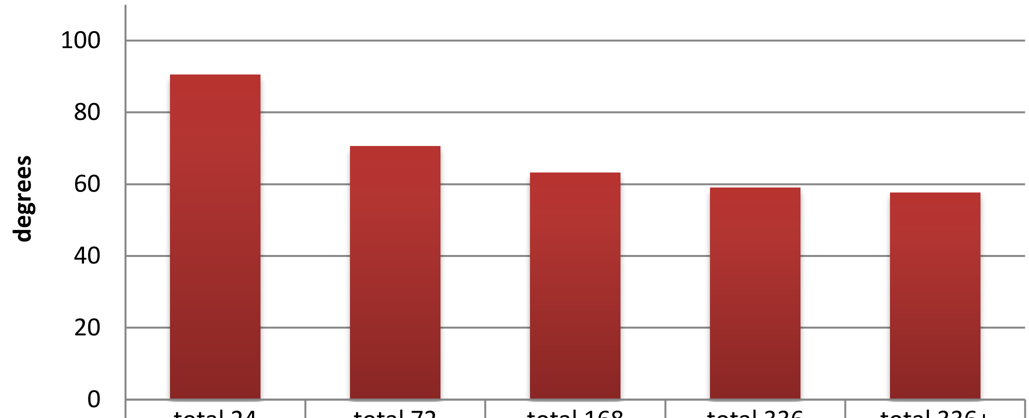


Figure 5.3 Some of the graphs produced out of the result tables (see 'Appendix C – result graphs' for all results).

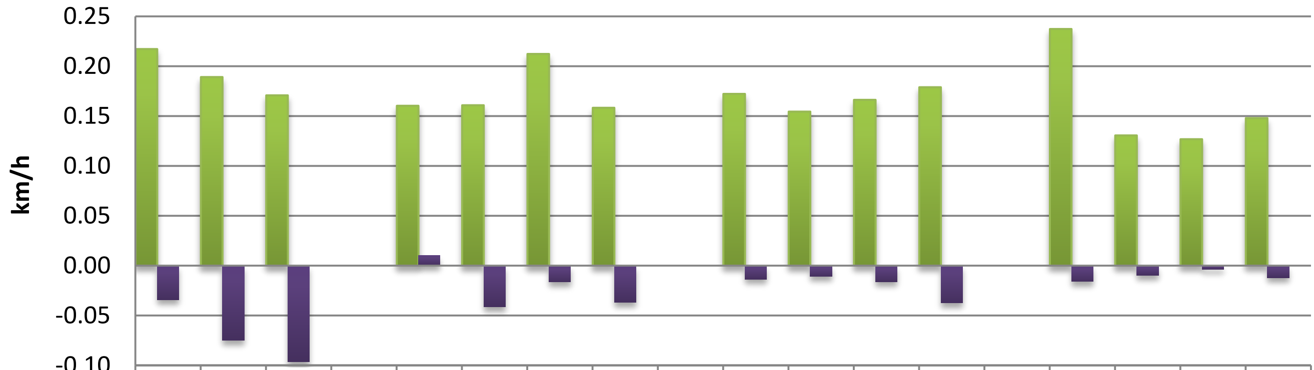
Figure 5.4 gives an example of what can be found in the results. It shows the changes in direction averaged over four years for the different ages of the crossed tracks. It can be observed that the changes in direction decrease with increasing age of the crossed track. This suggests for example that brown bears react stronger when crossing fresher tracks in terms of direction. A further investigation of tracks younger than 24 hours could be of interest when regarding this result, as the reactions seem to become stronger with decreasing age of the crossed track.



	total 24	total 72	total 168	total 336	total 336+
mean turnangle	90.46	70.53	63.20	59.00	57.63
sample size	202341	52357	68286	88076	261058

Figure 5.4 Mean turn angles averaged over four years.

Figure 5.5 shows graphs concerning the changes of speed after individuals cross the track of other individuals. The values are averaged over all ages of the crossed tracks. The green graphs show changes at the intersections, the purple ones changes after the intersections (compare with Figure 4.2). It can be observed that brown bears on average increased their speed directly at intersections. After the intersections however, they seem to keep the same speed or even decrease speed. There is more variability in values for changes in speed for one step after the intersection however, as standard deviations are higher.

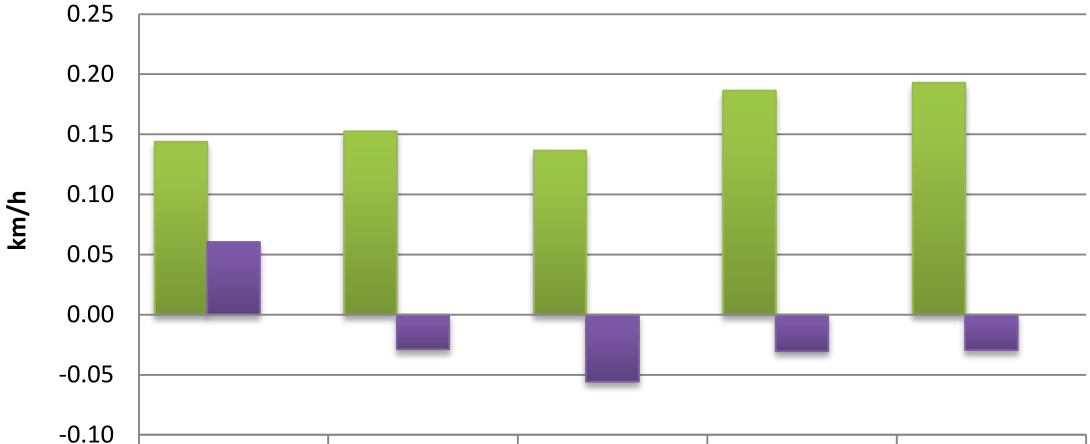


	F - F	F - M	M - F		F - F	F - M	M - F	M - M	F - F	F - M	M - F	M - M	F - F	F - M	M - F	M - M
	2006				2007				2008				2009			
mean speed diff1	0.22	0.19	0.17		0.16	0.16	0.21	0.16	0.17	0.15	0.17	0.18	0.24	0.13	0.13	0.15
SD speed diff1	0.85	0.92	0.85		0.78	0.84	1.09	0.62	0.71	0.74	0.91	0.92	1.12	0.86	0.81	0.84
mean speed diff2	-0.03	-0.08	-0.10		0.01	-0.04	-0.02	-0.04	-0.01	-0.01	-0.02	-0.04	-0.02	-0.01	0.00	-0.01
SD speed diff2	1.01	1.11	1.19		0.91	1.01	1.49	0.85	0.84	0.85	1.08	1.15	1.25	0.98	0.95	0.98
sample size	9554	345	723		22655	12697	15108	10784	35115	35470	28519	19841	111775	134761	133370	101401

SD=standard deviation

Figure 5.5 Changes in speed averaged for all ages of crossed tracks. The green graphs show reactions of brown bears directly at the intersections with the crossed track, the purple graphs show reactions after the intersection (compare with Figure 4.2).

The different ages of crossed tracks nonetheless, seem to have less influence on the changes of speed (Figure 5.6), opposed to changes in direction (Figure 5.4). All results visualised by graphs can be found in the 'Appendix C – result graphs'.

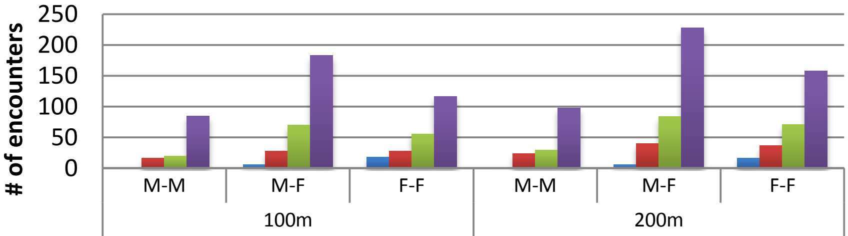


	total 24	total 72	total 168	total 336	total 336+
mean speed diff1	0.14	0.15	0.14	0.19	0.19
mean speed diff2	0.06	-0.03	-0.06	-0.03	-0.03
sample size	202341	52357	68286	88076	261058

Figure 5.6 Mean speed changes averaged over four years. The green graphs show changes at the intersection, the purple graphs after the intersection (compare with Figure 4.2).

5.2 RQ 2 - results

This research question examined encounters between individuals and how long they lasted. Furthermore, the exact date and time, as well as additional information on the individuals were included. In total, 628 coherent encounters were extracted for the spatial threshold of 100 m and 793 for the 200 m threshold (Figure 5.7). The output of the GIS analysis was again delivered in form of tables, ranging from single encounter positions to summarized results for sex and reproductive status combinations with different spatial thresholds. In contrast to the results of research question 1, due to processing issues the outputs of this analysis part did not have a direct spatial link. However, due to the exact date and time of the encounters, the connection to the spatial datasets could still be established if required (e.g. for visual analysis of encounters).



	M-M	M-F	F-F	M-M	M-F	F-F
	100m			200m		
2006	0	6	18	0	6	17
2007	17	28	28	24	40	37
2008	20	70	56	30	84	71
2009	85	183	117	98	228	158

Figure 5.7 Total number of encounters between individual brown bears on the study area in Sweden and Norway, divided by sex (M=male, F=female) and spatial threshold.

Figure 5.8 shows the outputs that were created. The basis is a table which contains an entry for each position that was part of an encounter. The further selections were conducted first of all by the two spatial thresholds used during the analysis. These selections were then further classified into encounters according to different sex- and reproductive status class combinations. Results have been processed into graphs (Figure 5.9). These graphs contain averaged durations of encounter for sex- and reproductive class combinations for each year.

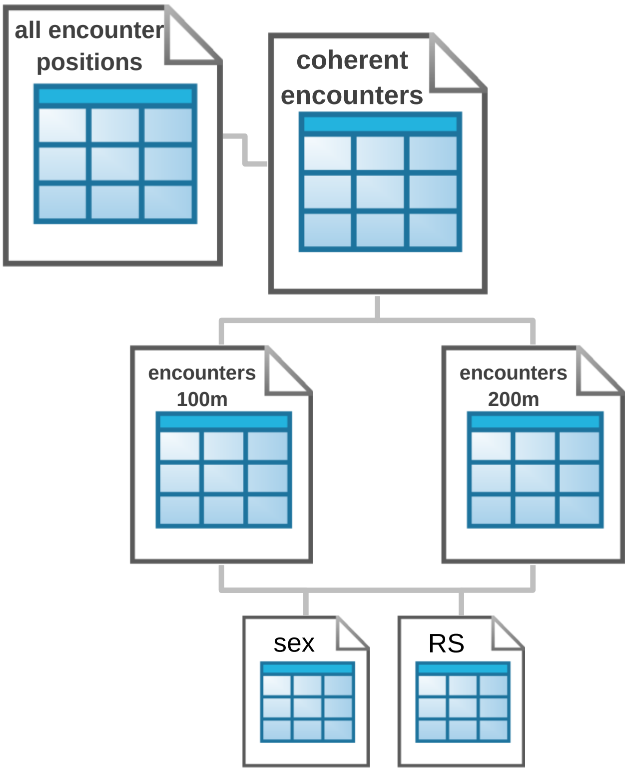


Figure 5.8 Schematic overview of produced output tables for research question 2 (per year).

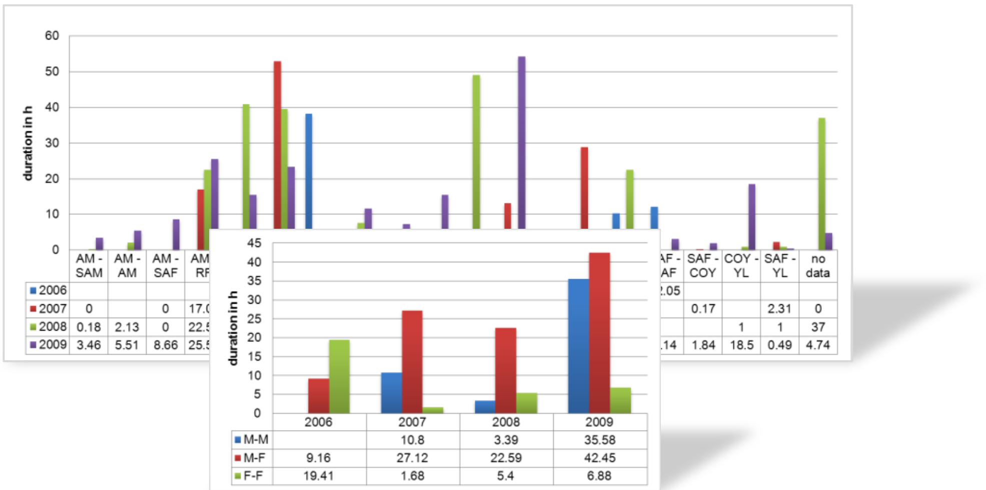
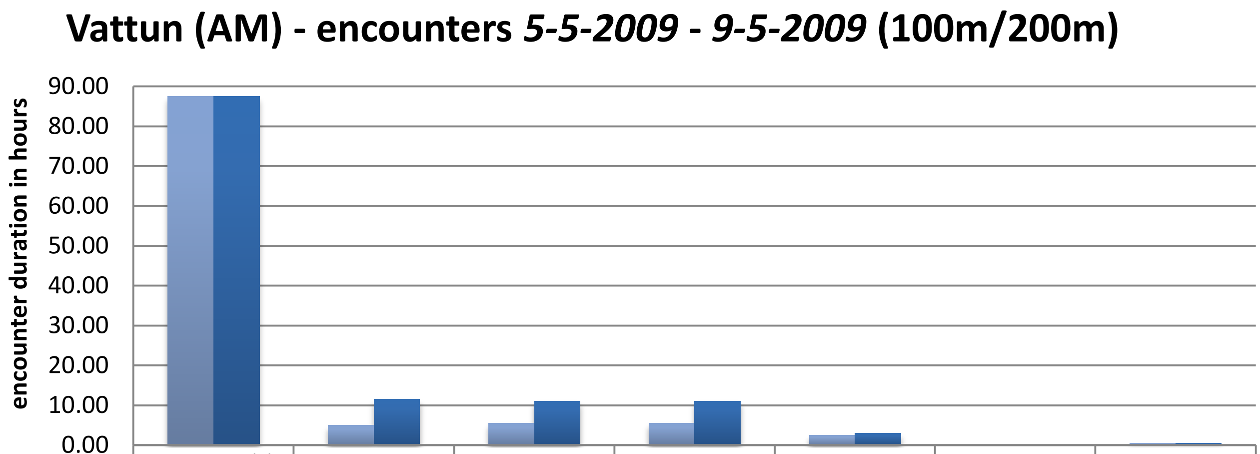


Figure 5.9 Example graphs of results for research question 2 (durations of encounters with 100 m spatial threshold for brown bear sex and reproductive class combinations). See 'Appendix C – result graphs' for all results.

Figure 5.10 presents an extract of the results for encounters with both spatial thresholds, showing what happened around a possible family breakup. It is known from the base data that the reproductive status of bear 'W0004' changed from 'YL' to 'RF' around May 5th/6th 2009. The graph on the right shows the encounters of bear 'W0805', an adult male, around this date. It can be seen, that he first encounters the mother, later on also her offspring ('W0810', 'W0811', 'W0812'). His encounter with the yearlings lasts around 5.5/11 hours (100 m/200 m threshold), whereas he stays with the mother for almost 90 hours. After these encounters, the yearlings did not return to the mother. The results for the different spatial thresholds are similar, only the extracted encounters between the adult male and the yearlings last around 5.5 hours instead of 11 hours for the 100 m threshold. In a next step, the encounters of the offspring could be analysed/presented in the same way, showing their behaviour after this obvious family breakup.

All the prepared graphs can be found in 'Appendix C – result graphs'.



	W0004, YL (3) 6-5-2009 00:00:27	W0810, SAM 6-5-2009 05:30:23	W0811, SAM 6-5-2009 05:00:11	W0812, SAM 6-5-2009 05:00:11	W0827, AM 5-5-2009 18:00:12	W0827, AM 7-5-2009 20:31:05	W0827, AM 8-5-2009 16:00:41
encounters 100 m	87.51	5.00	5.50	5.50	2.52	0.00	0.49
encounters 200 m	87.51	11.50	11.00	11.00	3.00	0.00	0.49

Figure 5.10 Extract of the encounters of an adult male for the period of five days showing what happened at a possible family breakup. The graph shows results (and differences in results) for the two spatial thresholds applied for encounters (100 m and 200 m).

5.3 Information leaflet for expert validation

The analysis produced various results regarding the research questions. However, the data output of this research showed ecological behaviour of brown bears and will be interpreted by experts. For this reason, it is not yet clear, whether the methods applied during analysis and the results themselves are feasible and of use regarding further ecological analysis and interpretation. Therefore, an information leaflet (Figure 5.11; Appendix D – Information leaflet), divided into three sections was designed for validation by experts. The first section contained a general introduction and explained the implemented methods. This was a simplified description of how the analysis was conducted and results were obtained. The second section then presented selected results. The last section provided various questions to the experts, which were related to how the research had been conducted and whether the methods and results were feasible/valid. These questions have been discussed and answered by five experts from the SBBRP and are presented in the next chapter.

Figure 5.11 Title page of the information leaflet created for expert validation.

5.4 Conclusion

The models and scripts which have been implemented during the analysis successfully delivered results concerning the research questions. It is possible to implement the chosen spatio-temporal concepts in a GIS and to apply them on the data provided by the SBBRP. Both, changes in speed and bearing after intersecting tracks have been extracted and encounters were found and their duration was determined. An interesting and no yet investigated item concerns the use of different threshold values, both spatial and temporal, and to analyse their influence by means of a sensitivity analysis. The different threshold values for encounters already showed differences in amount and length of (some) encounters (see also 'Appendix C – result graphs - RQ 2 – encounters' for all results), which gives an idea of the influence of the impact of the parameter settings. The question of whether or not these results are meaningful from an ecological point of view will be answered in the next chapter. From a GIS perspective, however, the methodology and analysis produced feasible results, although there may still be room for improvement regarding implementation, methods, data and preparation of results. The results may be used to find events like family breakups (Dahle and Swenson, 2003a) or infanticide (Swenson et al., 1997), the analysis itself can be applied on future tracking data or even on movement data of other species.

6 Expert validation

This chapter presents the feedback of the experts from the SBBRP on the information leaflet designed for expert validation. General comments as well as specific responses to the questions posed are summarized.

6.1 Introduction of experts

For this expert validation, an information leaflet has been created as described earlier. This was sent to five experts who are involved in the SBBRP. **Jon Swenson** is professor of ecology and natural resource management at the Department of Biology and Nature conservation at the Norwegian University of Life Sciences (UMB) in Ås. Furthermore, he is the scientific leader of the SBBRP. **Andreas Zedrosser** is a postdoctoral researcher at UMB, researcher at the University of Natural Resources and Life Sciences, Vienna, and member of the steering committee of the SBBRP. **Sam Steyaert** is a PhD student at the University of Natural Resources and Life Sciences, Vienna, and studies the mating system of the brown bear within the SBBRP. **Marcus Elfström** is a PhD student within the SBBRP, studying mechanisms behind the occurrence of bears close to people. **Shane Frank** recently finished his MSc in Forest Ecology and Management concluding with a thesis with the title '*Bears, Clear-cuts and Ants: Predicting bear use and movement among and within clear-cuts in Sweden during summer*'. He is now field assistant at the SBBRP field research station in Tackåsen, Sweden.

6.2 General comments and questions

Apart from answers to the questions presented in the information leaflet, further questions and comments regarding the research in general, but also concerning the research questions in detail came up. Within this first part, I will deal with the general comments as well as answers to the general questions of the information leaflet.

Position data

One of the first questions from the experts concerned the *position data* that I used for this research. A question was, whether only positions with 30-minutes intervals were used. Furthermore, whether the position data were filtered according to certain quality criteria (e.g. DOP < 5) was of interest. Another remark was about the spatial accuracy of the position data, also in combination with the chosen thresholds.

None of this filtering was applied during the research, as the influence of 'missing' positions (e.g. positions with DOP > than a threshold that have been filtered out) in the tracks on the analysis was not known. As only information on DOP and 2D/3D navigation was offered by the GPS collars (no clock error), this was difficult to define. DOP is not a direct measurement of accuracy, as it describes the quality of the current geometry of the satellites. This influences the data quality (lower DOP = higher accuracy), but it cannot be set in direct relation with spatial accuracy (e.g. DOP of 3 does not indicate spatial accuracy of 7m), as no clock error is offered in the recorded positions.

Sample size/differences between years

The sample size of individuals in 2006 seemed to be too small; especially the male-female distribution (1 male, 16 females) seemed to influence the results negatively. For further (ecological) analysis, results from this year should be removed. Furthermore, differences in results between years may be based on individual differences. Therefore, controlling for such individual variation will be important for further analysis.

Age classes

Sub adults were defined as bears younger than 5 years. However, it is known that some males have successfully mated at the age of three years and some females have been given birth the first time at the age of four years. This indicates a source of uncertainty, as this cannot be known for every individual. If it is known that a female younger than five years has given birth however, she cannot go back to reproductive status 'SAF' during the analysis and will obtain reproductive status 'RF' (e.g. in case of infanticide).

6.2.1 1. Are the results as presented understandable?

The experts found the results to be presented clearly and understandably. However, results on turn angles could have been presented a bit more easily to understand.

6.2.2 2. Are the generated results in general of interest/use for studying brown bear behaviour?

The experts found the results interesting for further studies of brown bear behaviour. If linked with biometric data (and reproductive status data in more detailed selections within results), the results will help to obtain a better understanding of mating behaviour and provide a better insight in the social organization of brown bears in general.

6.2.3 3. Do they deliver any new knowledge to you?

The results definitely provided new knowledge.

6.2.4 4. Can you think of any further (statistical) tests/analyses in order to find patterns in behaviour out of the results?

There are already some ideas on further analysis. They include comparisons of results with random walks, linkage of male quality (age, size, etc.) to encounter duration, encounter duration and frequencies in relation to mating strategies and infanticide or relations to dominance hierarchies and social systems. For further exploration of the results concerning these suggestions, multivariate statistical analyses like generalised linear models (GLM) or generalised linear mixed models (GLMM) could be applied.

6.2.5 5. Do you think that the results (of both research questions) can be used as a basis for an additional visual analysis of the spatial datasets?

This question was not quite clear to the experts. However, after further explanation it was agreed that it could be interesting for example, for comparing encounters between females with cubs or yearlings and adult males and actual infanticide events (e.g. for determination of successful infanticides by males). It can be a method for diving deeper into the bears' movements; also animations of trajectories are an option.

6.2.6 6. Can this analysis in your opinion also be applied/be of interest on/for other species, or even on interspecies applications?

The experts think that this analysis is definitely applicable for all species that are monitored with GPS collars and to other movement data. Furthermore, it could be interesting for studies focusing on interspecies interactions.

6.3 RQ 1 – expert validation

Remarks regarding the analysis mainly concerned the chosen ages of the crossed track. It was suggested that temporal time spans could be selected according to random walks or that additional selections within 24 hours could be applied (e.g. 12h, 6h, etc.). Even a continuous selection of track ages would be an option. This however, would be preferable to be implemented via a query tool in a database, as otherwise the selections would not be quite efficient. Other suggestions include comparisons of speeds after intersections with randomly selected speeds. Another option suggested by one of the experts could be a different speed calculation including further sub steps before and after intersections (by splitting up the step at the intersection) as well as using weights according to the length of these sub steps (Figure 6.1). Furthermore, there is the idea of removing intersections that are involved in encounters from the analysis. The anticipated maximum speed for brown bears of 56 km/h is too high (this relates to grizzly bears), the actual top speed may be around 35 km/h (Wikipedia, 2011). This nonetheless, did not influence the results of the analysis, as all values bigger than the set threshold for maximum speed were far higher, due to outliers.

The most striking comment regarding the results is the presentation of the turn angles. These should be presented as absolute values instead of relative ones. This means, that instead of showing changes in direction ranging from minus 180° to plus 180°, the range should be from 0° to 180°, as mean values are presented (the results graphs have been adapted and can be found in 'Appendix C – result graphs, RQ1 – turn angle'). Additionally, as many changes in direction have values between 165° and 180°, this will require further (ecological) investigation. Moreover, relative changes in speed rather than actual changes in speed could be compared, as this might give more information about how a bear reacted.

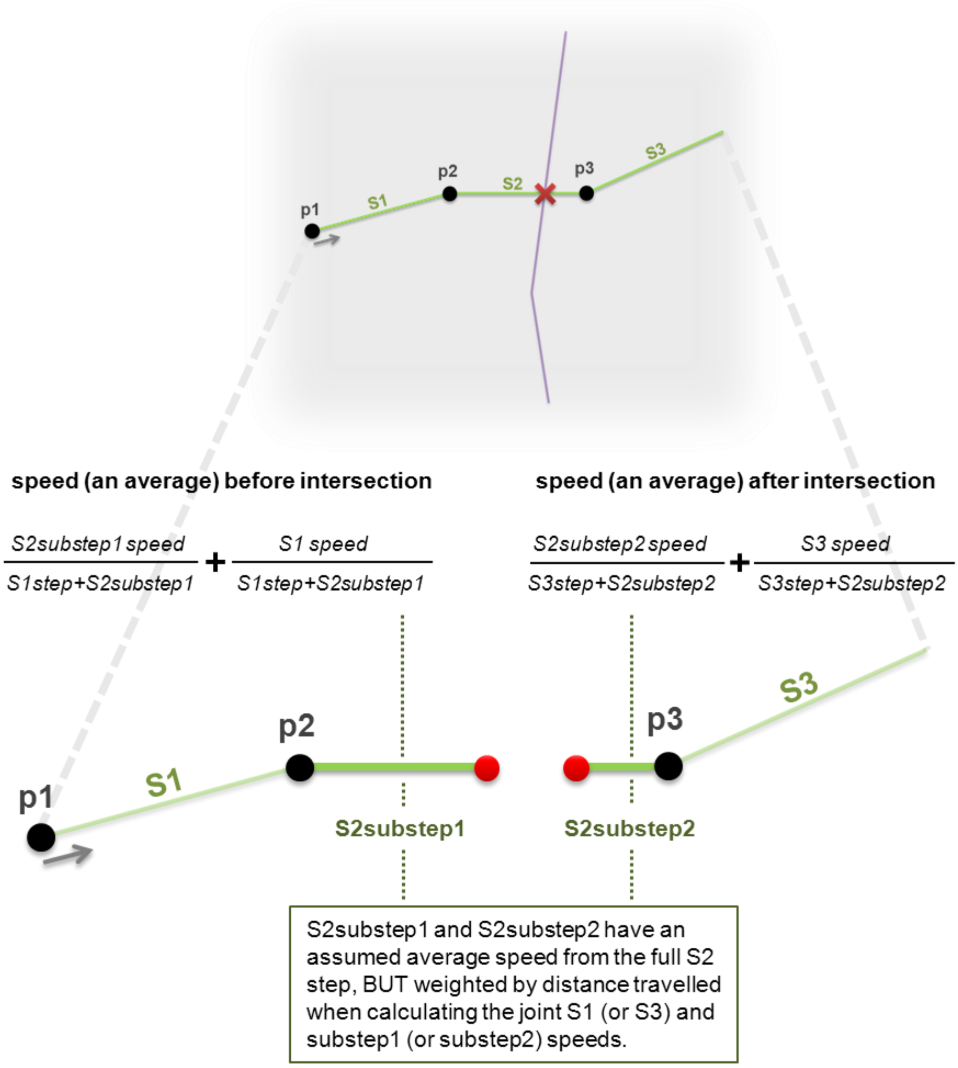


Figure 6.1 Alternative calculation of speeds before and after intersections of two brown bear tracks, as suggested by an expert.

6.3.1 7. The change in speed has been calculated in two versions. Is one of them preferable or are both of them of interest? Or should more steps before and after an intersection be taken into account (and eventually be averaged) for calculating a change in speed (implying that this also has to be adapted for the calculation of change in direction)?

Although in general both versions were accepted by the experts, it seemed to be a difficult question, as it is not known in detail how bears behave when crossing a track (Do they stop and inspect the track?, Do they react instantly?, etc.). The tendency however, was more towards favouring version two, and including more steps after an intersection was suggested (although not too many should be included, as bias through other factors could be introduced). A contrary version to that was the one mentioned earlier (compare Figure 6.1), which even analyses the step *at* the intersection in more detail.

6.3.2 8. The age of the crossed track has been grouped into five classes (<24 h, 24 h-72 h, 72 h-168 h, 168 h-336 h and >336 h). Are these selected temporal time spans useful/sufficient or would you prefer additional/different options (i.e. 6 h, 12 h, etc.)?

In general the chosen ages of the crossed tracks were considered to be useful, but it also was suggested to add further sub-divisions below 24 h (e.g. 6 h, 12 h). Besides that, a more linear classification by days can be an option (24 h, 48 h, 72 h, etc.). The most preferred solution would be a selection that is possible based on continuous intervals in hours (no pre-defined periods have to be chosen). It should also be considered, that additional factors like weather condition (dry/wet), type of surface (grass, moss, bare soil, etc.) can influence these results.

6.3.3 9. The presented graphs show results grouped together by sex for example. However, they are based on results of individual bears, meaning that you can access results for every single bear that was tracked and intersected the track of another tracked bear. Does that offer more possibilities of further analysis/interpretation for you, or are the grouped results more interesting?

Both, grouped and individual results were considered to be useful by the experts. For a more efficient analysis regarding time, one expert also suggested that individual data should only be considered to explain interesting results on a broader scale. Individual results however, can be set in relation with for example habitat, vegetation or terrain factors (which could affect movement parameters) for further analysis. This is also dependent on the topic of further research for which the results are used.

6.3.4 10. Would the information about change in direction be more valuable for you, if the bearing *after the crossing* of a track in relation to the bearing of the *crossed track* would also be known (meaning a bear could change to the same direction as the crossed track or to a completely different one; this also could be the basis for tracking analysis)?

All experts agreed that this information can be very valuable, especially regarding further analysis to find out whether/which bears track each other down/follow crossed tracks.

6.4 RQ 2 – expert validation

General comments mainly concerned the spatial thresholds with which encounters are defined. These parameters have to be justified in order be valid (both regarding spatial accuracy of positions). Another remark concerned the description of the 5-h threshold regarding coherent encounters. The value itself may be fine, but its description in the information leaflet was obviously not very clear.

6.4.1 11. Several spatial and temporal parameters were set during the analysis:

100 m/200 m spatial threshold/buffer around positions defining two individuals being 'together' at the same spatial location. According to my experience during fieldwork, the accuracy of the GPS collars is quite good. However, not all positions will have this high accuracy. Are these thresholds in your opinion well-chosen or could you even imagine to use for example a 50 m buffer?

In general these thresholds were accepted by the experts, especially the 100 m threshold. However, justification for setting up this value was needed (which probably can be offered by high accuracy of collars). Another approach can be a flexible threshold according to the mean speed of the particular bear and the distance it could possibly walk between two consecutive fixes according to that speed. A flexible threshold relating to DOP could be another option. Thresholds larger than 200 m were considered to be too high.

6.4.2 12. ±15 minutes temporal threshold around positions defining two individuals being 'together' at the same time

Is this a good value to consider two positions the same in time (considering mean logging frequencies; Figure 1) or should this threshold be flexible according to current logging frequency (of the individuals involved in the actual encounter) or mean logging frequencies per year for example?

This threshold was considered to be properly chosen, even though not all collars were always on a 10/30-minute schedule or positions may be missing. A flexible threshold (relating to mean logging frequencies or current logging schedule of collar) was regarded as more elegant; the question whether this would mean a gain in quality, remains however. According to experts this threshold should hold up against referees.

6.4.3 13. maximum 5 h between positions within coherent encounters:

This threshold makes sure that encounters will not be split up due to missing records of positions (i.e. 10 minutes logging frequency, but record 'n' was recorded at '14:00;17' and the next position 'n+1' was recorded at '15:10:04' due to GPS issues). On the other hand it can also just be that the individuals in fact are not close together for a certain period, but come together again. Would you consider the set threshold of 5 hours to be suitable or would you prefer a higher/lower value here?

Apart from requiring better explanation, this value seemed to be feasible, although this was considered to be a difficult question. It would be interesting to see how the results change with different values (e.g. lower threshold – more, shorter encounters?). This however, may also depend on the current logging frequencies and/or missing positions. Another option can be to choose biological data to define this threshold.

6.4.4 14. Can the obtained results (also per individual) be used for further ecological analysis, may they even give new insights in brown bear behaviour?

The results were considered to be extremely valuable, especially individual-based data linked with association durations. Statistical test were suggested to save time in analysis and to find further features to investigate further.

6.5 Additional questions

Some concluding questions regarding the research in general are listed below.

6.5.1 15. Would you like to use the analysis also for current and future movement data?

The experts plan to repeat this analysis also for the years 2010 and 2011 (current data).

6.5.2 16. Are the methods, how the results were obtained, valid in your opinion?

All experts agreed that the methods and results are valid and feasible.

6.6 Conclusion

The results of the expert validation were (unexpectedly) positive. Methods, parameters and results were regarded as being valid by the experts, although most responses appeared to be somewhat general (e.g. in regard to what kind of new knowledge can be obtained; this however, does not influence the results of this validation.). This validation not only fulfilled its purpose for validating the conducted research, it also ignited a discussion regarding alternative methods and settings for thresholds and parameters which have been chosen. This is important for further improvement of the methods and additional analysis in the future, as there may even be more potential in the analysis and results when improved in collaboration with experts, both from the ecological as well as from the GIS perspective. It furthermore fortifies that a sensitivity analysis may help to find the most suitable values for spatial and temporal threshold parameters.

7 Discussion, recommendations and conclusion

This is the concluding chapter of this thesis. A discussion regarding the implementation, the methods, the data and the results is provided as well as recommendations for future research. The chapter is completed with a conclusion, summing up this research.

7.1 Discussion

The objective of this research was achieved and results were produced, that were accepted by experts. This indicates that the methods which were developed, as well as the obtained results, are valid. However, as mentioned before, there is room for improvement on all levels (*implementation*, *methods*, *data* and *results*) of this research. As the analysis methods were implemented in ArcGIS (including extensions) and Python ***from scratch***, I learned a lot during this process. This means that some steps probably would have been conducted slightly differently now after finishing all analysis processes, due to new skills and knowledge obtained during the thesis work. Apart from factors concerning implementation, developed methods and preparation of results, there are also issues on a more abstract level relating to uncertainties in data, both demographic and positional data.

7.1.1 Implementation

When regarding the implemented methods in this research as an application, it probably can still be described as being a (working, but not most efficient) *prototype*. All scripts and models have been commented and described in order to ensure the repeatability of this project. Nonetheless, this may not be sufficient to be regarded as a user-friendly application. As the spatio-temporal analysis as implemented in ArcGIS and Python is complex, for non-GIS experts, processes, models and scripts may be difficult to understand. Therefore, a rework including the creation of a 'cookbook' for how to use the models and scripts in the analysis would improve the value of this research concerning re-usability.

Some of the processing steps were not possible to implement in the applied software, causing 'detours' by using custom programming in Python (compare e.g. problems with Spatial Join in '4.3 RQ 2 - methods'). In some cases, the produced scripts are faster than using standard tools offered by ArcGIS (e.g. point to line conversion including join of attributes, processing step 'IAa6createLines'), in other cases these scripts have a long processing time (mainly due to big size of input datasets). These scripts also can be optimized regarding the implemented algorithms, but possibly also regarding ArcGIS tools that have been used within them. Some of the created scripts could be joined together and not all of the databases which have been created in ArcGIS are required. Another item concerning increase in efficiency may be the demographic data. It was joined to the position data manually at the beginning of the analysis and was present in (almost) all datasets during the whole analysing process. By joining this demographic data to the results at the end instead of at the beginning, the size of the datasets in terms of file size could be reduced, probably leading to faster processing times. There may be more sources for optimization in detail, but not all of them can be mentioned here.

As ArcGIS 9.3 does not provide sufficient capabilities as a stand-alone tool for this kind of spatio-temporal analysis (meaning that without extensions and custom programming, this analysis would not have been possible), it seems worth considering the latest version ArcGIS 10 and/or alternative (open source) software packages or tools as mentioned earlier in '4.1 Methodological framework'. Another option can be the implementation of the methods in a spatial database such as open source PostGreSQL (PostgreSQL, 2011) with spatial PostGIS (PostGIS, 2011) extension. Such an implementation is based on a relational database management system which may offer faster processing of big datasets. Considering the increasing amounts of tracking data recorded by the SBBRP (but also in general), this is an option that has to be taken into account regarding future analyses.

7.1.2 Methods and data

The results as well as the outcome of the expert validation showed that the chosen spatio-temporal concepts and their implementation in a GIS for this research were successful. There are items however, which are worth discussing. One part concerns the data that has been used for this analysis. All available positions within the mating season were used for this study. Admittedly, these positions can be filtered in regard to certain 'quality criteria' before or during analysis, such as positions that have a DOP smaller than a certain threshold (e.g. DOP < 5) or only positions on 10- or 30-minute logging intervals. This can be implemented during the pre-processing or even during the analysis by adding certain selection criteria. This may increase trust in the results concerning accuracy However, the effect on 'excluding' positions from trajectories on the results should be investigated before/while conducting the analysis.

Another point of discussion is the definition of the parameters for spatial and temporal thresholds, which had to be set up during the analysis. It would be of interest to determine, how variations of these parameters influence the results. The comparison between random encounters with different spatial thresholds (100 m/200 m) showed that the 200 m threshold can include encounter positions that would be missed with the 100 m threshold (this can be detected by visual analysis of the encounter positions). Due to lack of time, further comparisons were not possible to be analysed during this thesis work, as major parts of the analysis have to be repeated in order to do so. In general, the values chosen during analysis were regarded as valid by the experts, but nonetheless, there may be further options worth to be investigated (compare '6 Expert validation').

Another item that has to be taken into account is that it is not known what actually happens between two consecutive GPS fixes. The steps are represented and handled as straight lines between two positions. This is hardly the case in reality, however, meaning that possibly not all extracted intersections really did occur, or intersections can be missed during analysis (Figure 7.1). Furthermore, it is not known how a bear reacts directly at the track it crosses (Does it stop for inspection? Does it immediately continue its movement?; also dependent on age of crossed track, reproductive status, etc.). These, apart from more or less known issues like GPS (in-) accuracy, are further uncertainties in the spatial data, which could possibly be taken care of by introducing further threshold variables. A remaining source of error will still be the fact that (small) outliers in positional data cannot be distinguished from true positions. All of these items may be considered as being on a very small scale and detailed, but to a certain degree uncertainty will be present and may have to be accepted with current technology and techniques. Higher spatial accuracy and higher logging frequencies can decrease this to a certain extent.

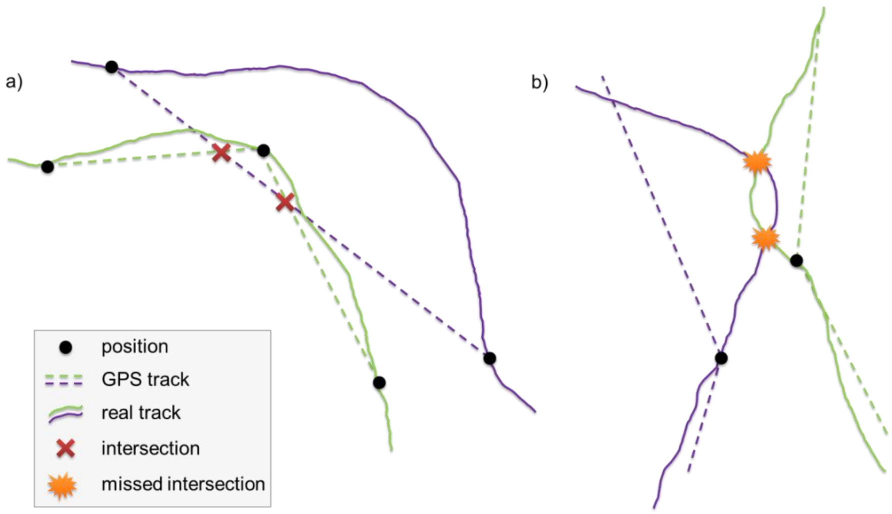


Figure 7.1 a) Intersections may be detected which do not occur in reality (such a situation could even indicate avoidance of another track); b) intersections occurring in reality may be missed.

Another source of uncertainty regarding further ecological analysis is introduced by the demographic data provided by the SBBRP. On the one hand information is not available for all tracked individuals (compare 3.3.3 Preprocessing). On the other hand, information like reproductive status may change during the mating season (e.g. a female loses her cubs due to infanticide). Moreover, sub adults are defined according to the literature as being bears younger than 5 years. As mentioned before, it is known that males have been mating successfully already at the age of three years and females have given birth at the age of four years. Detailed analysis on individual encounters in the results however, may help to detect for example possible changes in reproductive status.

7.1.3 Results

The results as described and presented in this thesis show that the implementation of spatio-temporal concepts on this tracking data is possible. Outputs for both research questions were produced and successfully validated by experts. However, these outputs can only be the basis for further statistical and ecological analysis and interpretation (compare '6 Expert validation'), which is not part of this thesis.

One critique on how the results have been processed and presented to the experts concerns the changes in direction (turn angles). As mentioned earlier, they should be presented rather as absolute values than as relative values, as this may falsify the results of turn angles (as the result graphs show mean values). This nonetheless can be changed easily, due to availability of all the raw data from the results. Another suggestion is to increase the age classes of crossed tracks, especially below 24h. An optimal solution would probably be a continuous selection method as suggested by one of the experts. A query tool (like SQL in a database) can be a powerful solution to not only this issue, but also for more sophisticated selections of encounters according to for example reproductive status combinations.

7.1.4 Spatio-temporal concepts

The implementation of the selected spatio-temporal concepts '*full co-incidence in space and time*' and '*lagged co-incidence in space and time*' proved to be useful, as they delivered feasible results. The definitions, however, could be adapted according to this thesis work, which included both spatial and temporal thresholds:

- **Full co-incidence:** positions are within spatial and temporal thresholds (spatial and temporal distances < threshold)
- **Lagged co-incidence:** positions are within a spatial threshold, but not within temporal a threshold (spatial distance < threshold, temporal distance > threshold)

However, these concepts are so logic in their nature, they may even be applied in studies without being aware of (compare e.g. Stenhouse et al., 2005).

7.1.5 Sensitivity analysis

As already mentioned before and also shown by results for research question 2 with different spatial thresholds, the setting of parameters plays an important role in this analysis. Figure 7.2 shows a possible setup for a sensitivity analysis concerning the parameters for research question 2. It shows the two combinations of spatial and temporal thresholds that have been applied during this research already. However, there are more possible options, whereas each possibly produces different results. Even a second temporal axis could be added here, introducing the second temporal threshold that has been used to determine coherent encounters (compare 'RQ 2 - methods'). The results of such a sensitivity analysis could then also be the basis of an investigation on flexible thresholds, which could be set in relation to DOP values.

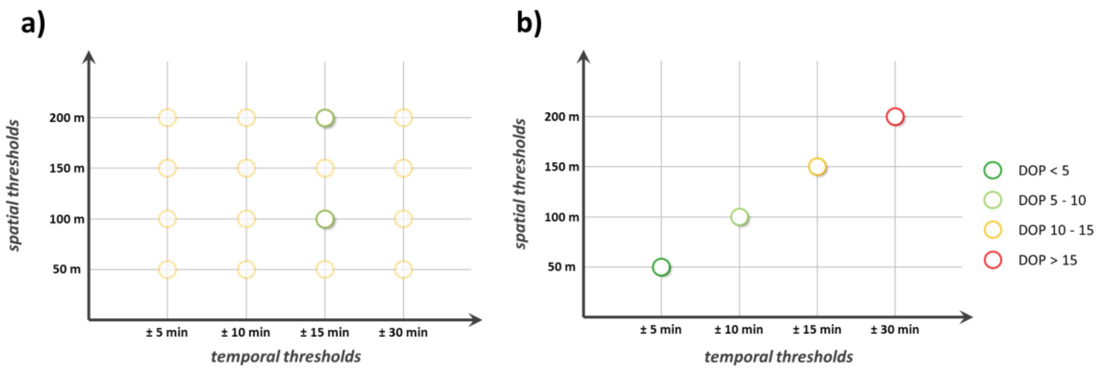


Figure 7.2 a) Possible additional combinations of spatial and temporal thresholds for research question 2 that could be applied during a sensitivity analysis (orange rings) and threshold combinations that were applied already (green rings). b) Possible setting for flexible thresholds related to DOP after sensitivity analysis.

7.1.6 Ecological

An ecological discussion should be left to brown bear experts, as this is not an ecological thesis. The results of this research are available for further statistical and ecological analysis as mentioned before.

7.2 Recommendations

The recommendations are closely related to the items mentioned in the discussion above and are summarized in Table 7.1. They are divided in four levels again, which are *data*, *implementation*, *methods* and *results* and contain suggestions how to proceed for further research on this topic.

Table 7.1 Recommendations for all levels of research.

level	recommendations
data	• data can be filtered according to certain quality criteria (DOP, logging frequency) • logging frequency should be as constant as possible • additional proximity sensors on the collars (e.g. VECTRONIC UHF ID tag) can detect and record encounters, but also switch to higher logging frequency during an encounter for more detailed position data for analysis • completeness of demographic data should be improved
implementation	• room for improvement in current implementation (merge scripts, less databases, etc.) • more custom programming may improve efficiency of procedures • check possibility of implementation via alternative (open source) tools regarding more efficient handling of massive movement datasets
methods	• check influence of different parameter settings on results (spatial and temporal thresholds) by means of sensitivity analysis • check possibility of flexible thresholds related to DOP quality • already implemented methods and obtained results can be used as basis for further spatio-temporal analysis (e.g. Do/which bears track each other down?, How long in distance and time?, etc.)
results	• use raw and averaged results for further statistical and ecological analysis as they provide new knowledge regarding the ecology of the brown bear (according to expert validation) • there is big potential in the movement data gathered by the SBBRP, not only regarding further spatio-temporal analysis

7.3 Conclusion

To sum up this research, I return to the objective and the research questions. The objective of this thesis was to find out, whether spatio-temporal concepts are applicable for animal tracking data, especially for analysing brown bear interactions during the mating season, to obtain new information about the brown bear mating system. The question was, whether these spatio-temporal concepts can be applied in a GIS in order to obtain feasible results. This question can be clearly answered with a "*Yes!*". The objective has been achieved, as this research has shown, that spatio-temporal concepts can be applied on animal movement data in order to gain new knowledge about their behaviour. A pre-condition for that is, on the one hand, tracking data that offer a certain level of both spatial and temporal resolution. On the other hand, the results of such an analysis have to be further processed in terms of statistics and by adding ecological knowledge. A sensitivity analysis on the parameters that have to be set for thresholds can furthermore improve the quality of the results.

The literature study provided a well-founded overview on both spatio-temporal analysis and concepts, providing a good basis for selecting suitable concepts for this research. The chosen concepts may appear to be rather simple by definition, but this proved to be completely sufficient for answering the two main research questions. Results for both of them were obtained, after the spatio-temporal concepts have been implemented in GIS analysis. On top of that, experts from the SBBRP validated the methods as well as the results and regarded them not only as being feasible, but also being valuable for brown bear research and delivering new knowledge on the brown bear mating season. This indicates that the methods developed can also be applied on movement data of other species; even analysis on interspecies interactions is conceivable.

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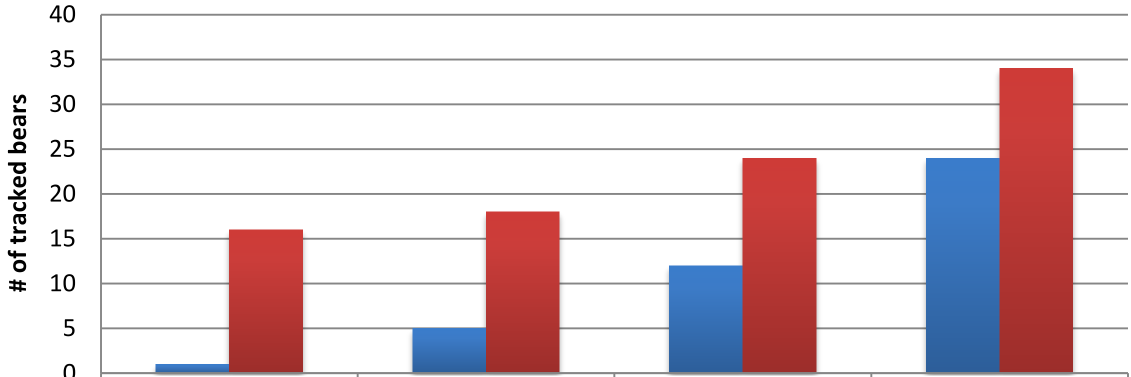
Appendix

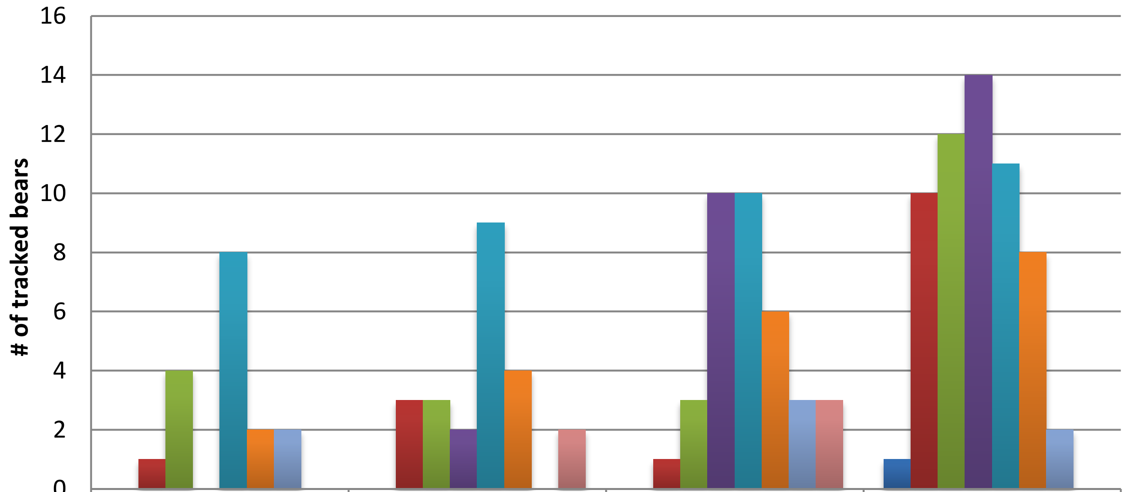
Appendix A – basic references

Number of male and female bears tracked



	2006	2007	2008	2009
males	1	5	12	24
females	16	18	24	34

Number of bears tracked according to reproductive status



	2006	2007	2008	2009
D	0	0	0	1
SAM	1	3	1	10
SAF	4	3	3	12
AM	0	2	10	14
RF	8	9	10	11
COY	2	4	6	8
YL	2	0	3	2
no data	0	2	3	0

D=dead bear, SAM=sub adult male, SAF=sub adult female, AM=adult male, RF=reproductive female, COY=female with cubs, YL=female with yearlings

Appendix B – Table of content for models and scripts on DVD

All ArcGIS models and Python scripts that have been created during this thesis work are present for further reference, but have not been included in this report. They can be found on the DVD that is delivered with this report.

Processes pre-processing

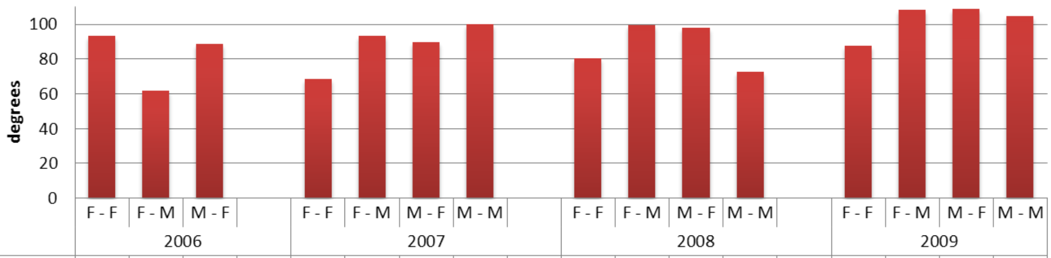
Processes research question 1

Processes research question 2

Appendix C – result graphs

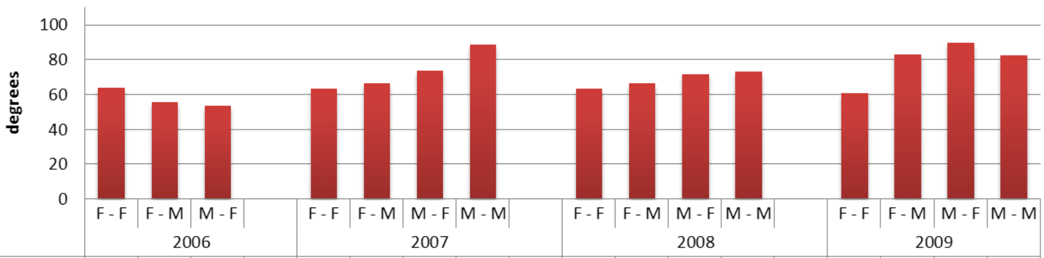
RQ1 – turn angle

Mean turn angle *24h*



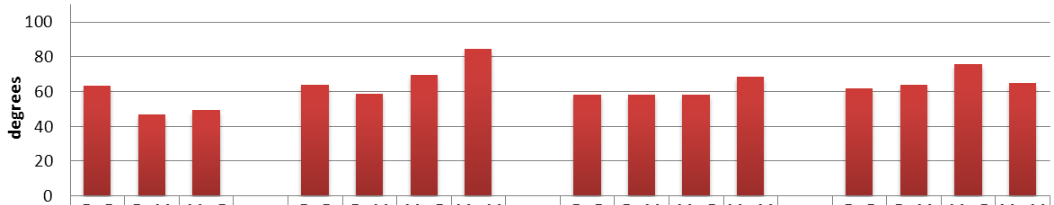
	2006 F - F	2006 F - M	2006 M - F	2007 F - F	2007 F - M	2007 M - F	2007 M - M	2008 F - F	2008 F - M	2008 M - F	2008 M - M	2009 F - F	2009 F - M	2009 M - F	2009 M - M
mean turnangle	93.36	61.79	88.67	68.55	93.55	90.00	100.03	80.51	99.75	98.11	72.70	87.52	108.34	109.15	104.93
sample size	1089	82	59	1064	1753	1984	1481	2448	5462	8293	1540	12019	61819	63555	39693
SD* turnangle	55.05	51.53	55.79	51.53	57.94	55.21	54.66	55.74	56.79	58.41	52.75	57.16	55.48	55.33	56.15

Mean turn angle *72h*



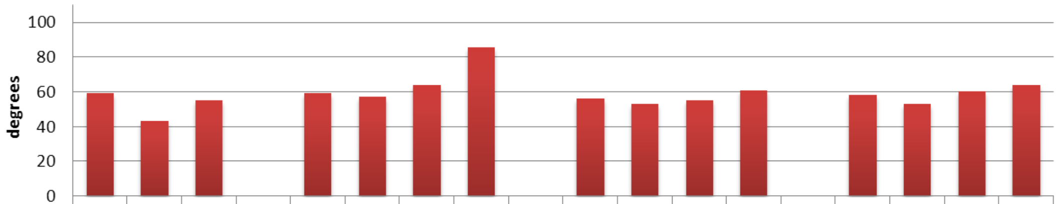
	2006 F - F	2006 F - M	2006 M - F	2007 F - F	2007 F - M	2007 M - F	2007 M - M	2008 F - F	2008 F - M	2008 M - F	2008 M - M	2009 F - F	2009 F - M	2009 M - F	2009 M - M
mean turnangle	63.91	55.81	53.91	63.46	66.41	73.85	88.96	63.57	66.39	71.80	73.22	60.75	83.25	89.95	82.65
sample size	545	19	15	1890	1099	1116	1332	2746	2141	2518	1665	8404	10443	10717	7707
SD turnangle	51.56	48.40	47.33	49.27	51.56	52.52	52.43	50.76	50.86	56.32	55.15	49.96	57.63	59.38	57.40

Mean turn angle *168h*



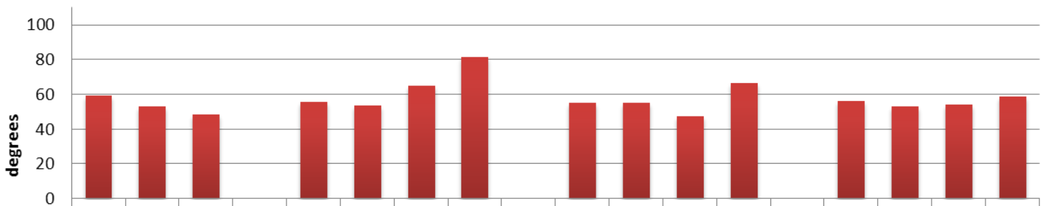
	2006 F - F	2006 F - M	2006 M - F	2007 F - F	2007 F - M	2007 M - F	2007 M - M	2008 F - F	2008 F - M	2008 M - F	2008 M - M	2009 F - F	2009 F - M	2009 M - F	2009 M - M
mean turnangle	63.60	46.69	49.74	63.86	58.89	69.81	84.49	58.20	58.48	58.51	68.71	62.01	64.15	76.04	64.82
sample size	1213	73	70	3054	1647	1906	1877	4621	3279	3441	2063	14180	10404	12067	8391
SD turnangle	49.91	39.40	43.07	51.15	47.33	51.72	52.85	47.64	50.14	52.86	55.06	51.42	52.23	57.00	52.47

Mean turn angle *336h*



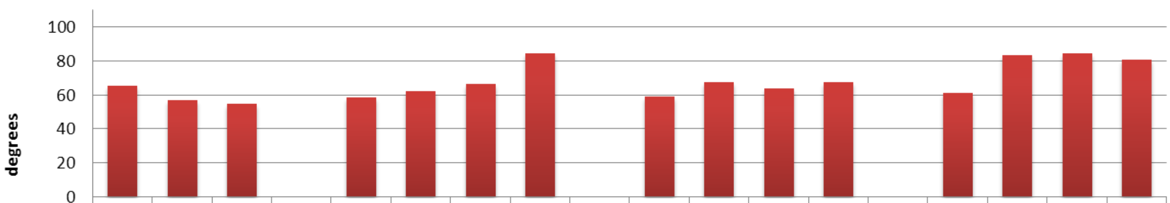
	2006 F - F	2006 F - M	2006 M - F	2007 F - F	2007 F - M	2007 M - F	2007 M - M	2008 F - F	2008 F - M	2008 M - F	2008 M - M	2009 F - F	2009 F - M	2009 M - F	2009 M - M
mean turnangle	59.42	43.56	55.38	59.35	57.29	63.86	85.56	56.04	53.06	54.97	60.68	58.13	53.40	60.15	64.22
sample size	1705	55	173	4571	2269	2427	2011	6614	5251	4825	3535	19324	12138	12700	10478
SD turnangle	47.52	42.66	44.20	49.37	47.30	51.06	51.67	45.51	46.08	50.22	52.38	49.51	46.07	52.02	52.24

Mean turn angle *336h+*



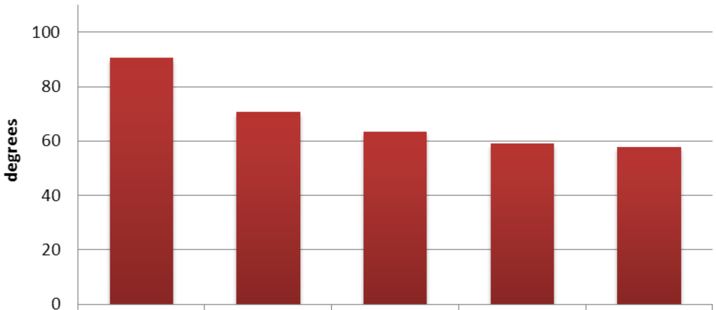
	2006 F - F	2006 F - M	2006 M - F	2007 F - F	2007 F - M	2007 M - F	2007 M - M	2008 F - F	2008 F - M	2008 M - F	2008 M - M	2009 F - F	2009 F - M	2009 M - F	2009 M - M
mean turnangle	59.45	53.10	48.49	55.83	53.61	64.95	81.68	55.37	55.23	47.54	66.41	56.37	53.39	54.36	58.72
sample size	5002	116	406	12076	5929	7675	4083	18686	19337	9442	11038	57848	39957	34331	35132
SD turnangle	50.70	47.96	40.70	47.12	46.36	50.94	51.04	45.77	45.62	45.76	54.44	48.37	47.03	48.80	49.15

Mean turn angle (total)



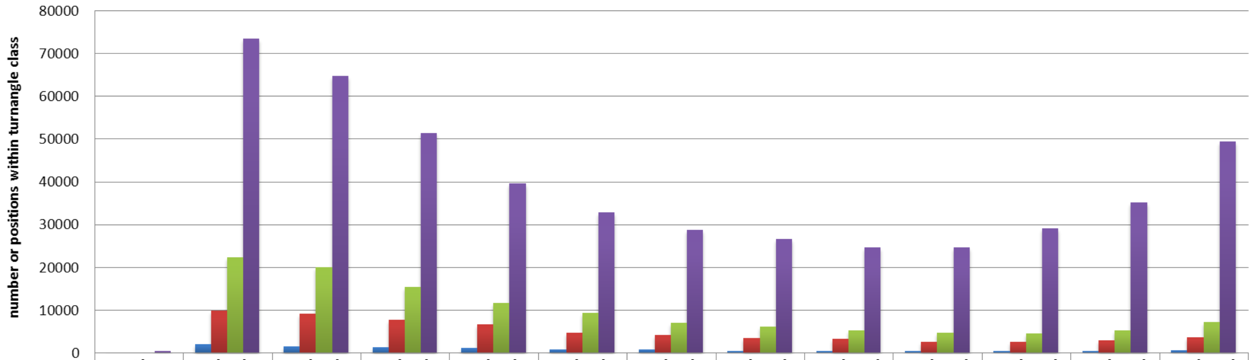
	2006 F - F	2006 F - M	2006 M - F	2007 F - F	2007 F - M	2007 M - F	2007 M - M	2008 F - F	2008 F - M	2008 M - F	2008 M - M	2009 F - F	2009 F - M	2009 M - F	2009 M - M
mean turnangle	65.49	56.88	54.81	58.46	62.52	66.82	84.74	59.27	67.43	64.02	67.56	61.55	83.67	84.60	80.66
sample size	9553	534	534	22654	13900	13900	10782	35111	31989	31989	19839	111758	133951	133951	101304
SD turnangle	51.81	48.11	45.86	48.41	50.90	51.71	53.43	48.23	52.96	55.71	54.48	51.36	58.30	59.08	57.24

Mean turn angle averaged over 4 years



	total 24	total 72	total 168	total 336	total 336+
mean turnangle	90.46	70.53	63.20	59.00	57.63
sample size	202341	52357	68286	88076	261058

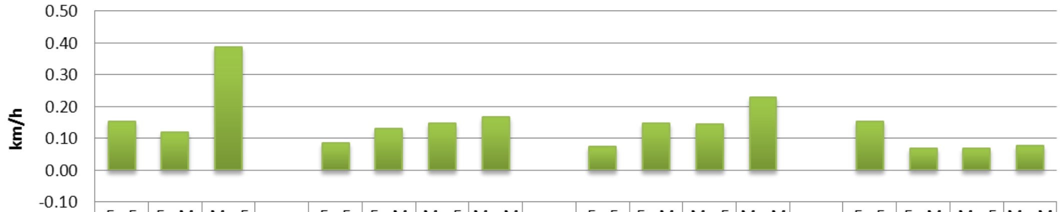
Frequency distribution of turn angle classes after intersections



	0°	0°-15°	15°-30°	30°-45°	45°-60°	60°-75°	75°-90°	90°-105°	105°-120°	120°-135°	135°-150°	150°-165°	165°-180°
turnangle_2006	72	2014	1604	1357	1201	839	723	498	404	411	529	380	590
turnangle_2007	139	9877	9155	7713	6724	4817	4237	3485	3354	2673	2521	2919	3630
turnangle_2008	83	22320	20022	15404	11656	9337	6989	6151	5299	4737	4473	5334	7140
turnangle_2009	367	73507	64853	51396	39720	32816	28799	26575	24730	24626	29237	35240	49441

RQ1 – speed1

Mean speed diff1 *24h*

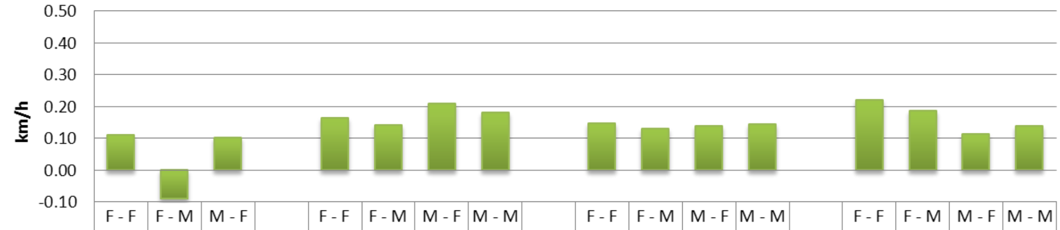


	2006				2007					2008					2009			
	F - F	F - M	M - F		F - F	F - M	M - F	M - M		F - F	F - M	M - F	M - M		F - F	F - M	M - F	M - M
mean speed diff1	0.15	0.12	0.39		0.08	0.13	0.15	0.17		0.07	0.15	0.14	0.23		0.15	0.07	0.07	0.08
sample size	1089	82	59		1064	1753	1984	1481		2448	5462	8293	1540		12019	61819	63555	39693
SD speed diff1 *	0.75	0.86	0.76		0.75	0.75	0.66	0.52		0.68	0.64	0.78	1.08		1.01	0.52	0.45	0.46

Mean speed diff1 *72h*

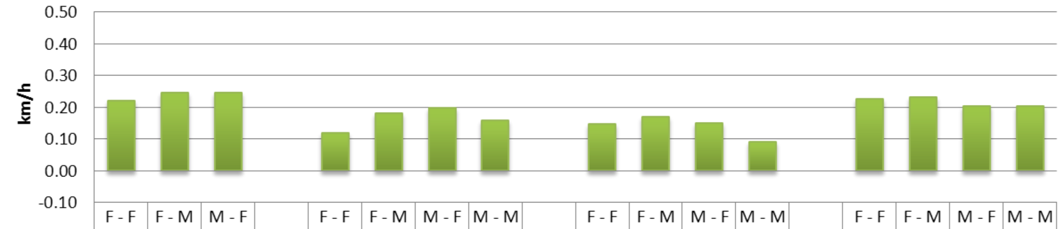
	2006			2007				2008				2009			
	F - F	F - M	M - F	F - F	F - M	M - F	M - M	F - F	F - M	M - F	M - M	F - F	F - M	M - F	M - M
mean speed diff1	0.25	0.45	0.02	0.12	0.13	0.18	0.19	0.09	0.15	0.07	0.14	0.15	0.12	0.11	0.13
sample size	545	19	15	1890	1099	1116	1332	2746	2141	2518	1665	8404	10443	10717	7707
SD speed diff1	0.79	0.93	0.93	0.71	0.79	1.08	0.61	0.68	0.84	0.88	0.85	1.02	0.91	0.75	0.80

Mean speed diff1 *168h*



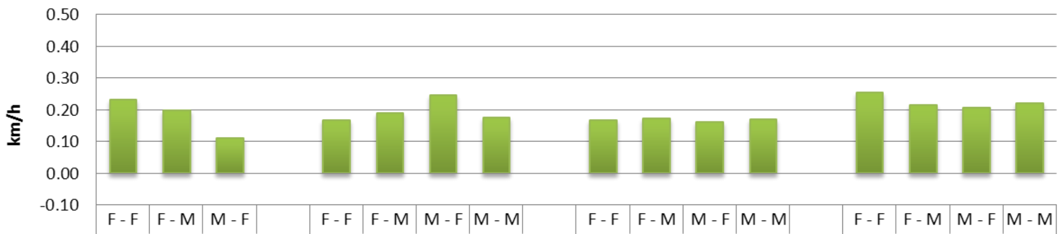
	2006			2007				2008				2009			
	F - F	F - M	M - F	F - F	F - M	M - F	M - M	F - F	F - M	M - F	M - M	F - F	F - M	M - F	M - M
mean speed diff1	0.11	-0.09	0.10	0.17	0.14	0.21	0.18	0.15	0.13	0.14	0.15	0.22	0.19	0.11	0.14
sample size	1213	73	70	3054	1647	1906	1877	4621	3279	3441	2063	14180	10404	12067	8391
SD speed diff1	0.81	0.62	0.91	0.76	0.87	0.92	0.62	0.70	0.77	0.93	0.99	1.09	1.11	0.93	0.96

Mean speed diff1 *336h*



	2006			2007				2008				2009			
	F - F	F - M	M - F	F - F	F - M	M - F	M - M	F - F	F - M	M - F	M - M	F - F	F - M	M - F	M - M
mean speed diff1	0.22	0.25	0.25	0.12	0.18	0.20	0.16	0.15	0.17	0.15	0.09	0.23	0.23	0.20	0.20
sample size	1705	55	173	4571	2269	2427	2011	6614	5251	4825	3535	19324	12138	12700	10478
SD speed diff1	0.98	0.76	0.86	0.80	0.89	0.88	0.60	0.72	0.75	0.85	0.93	1.07	1.19	1.13	1.08

Mean speed diff1 *336h+*

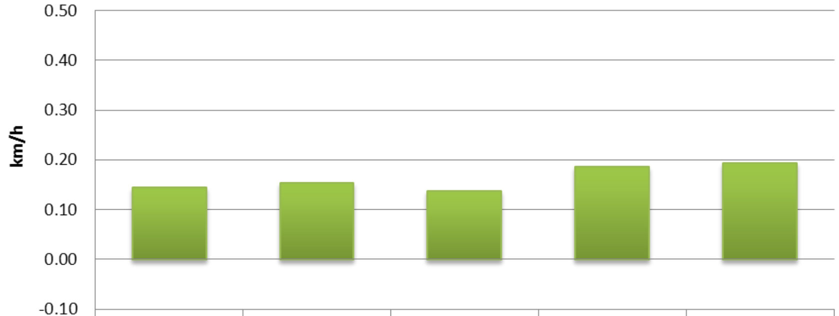


	2006			2007				2008				2009			
	F - F	F - M	M - F	F - F	F - M	M - F	M - M	F - F	F - M	M - F	M - M	F - F	F - M	M - F	M - M
mean speed diff1	0.23	0.20	0.11	0.17	0.19	0.25	0.18	0.17	0.17	0.16	0.17	0.25	0.22	0.21	0.22
sample size	5002	116	406	12076	5929	7675	4083	18686	19337	9442	11038	57848	39957	34331	35132
SD speed diff1	0.81	0.66	0.84	0.81	0.87	1.17	0.75	0.64	0.72	0.81	0.87	1.17	1.06	1.00	1.04

Mean speed diff1 (total)

	2006			2007				2008				2009			
	F - F	F - M	M - F	F - F	F - M	M - F	M - M	F - F	F - M	M - F	M - M	F - F	F - M	M - F	M - M
mean speed diff1	0.22	0.19	0.17	0.16	0.16	0.21	0.16	0.17	0.15	0.17	0.18	0.24	0.13	0.13	0.15
sample size	9553	534	534	22654	13900	13900	10782	35111	31989	31989	19839	111758	133951	133951	101304
SD speed diff1	0.85	0.92	0.85	0.78	0.84	1.09	0.62	0.71	0.74	0.91	0.92	1.12	0.86	0.81	0.84

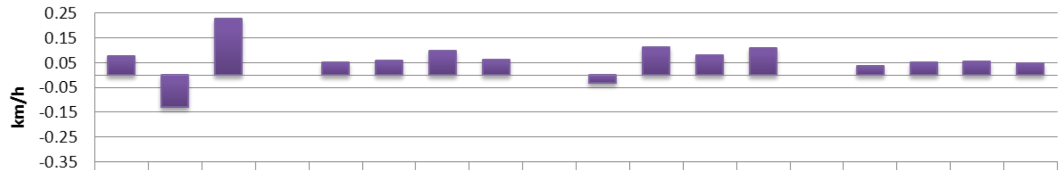
Mean speed change averaged over 4 years



	total 24	total 72	total 168	total 336	total 336+
mean speed diff1	0.14	0.15	0.14	0.19	0.19
sample size	202341	52357	68286	88076	261058

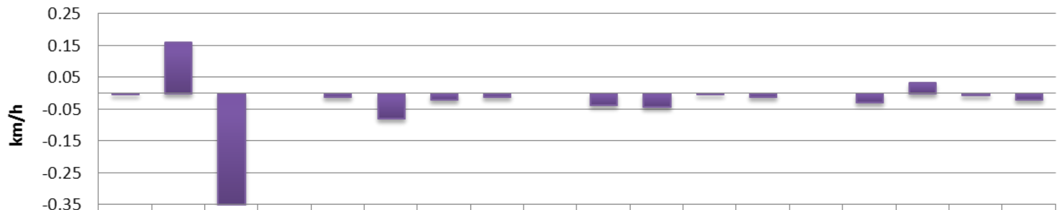
RQ 1 – speed2

Mean speed diff2 *24h*



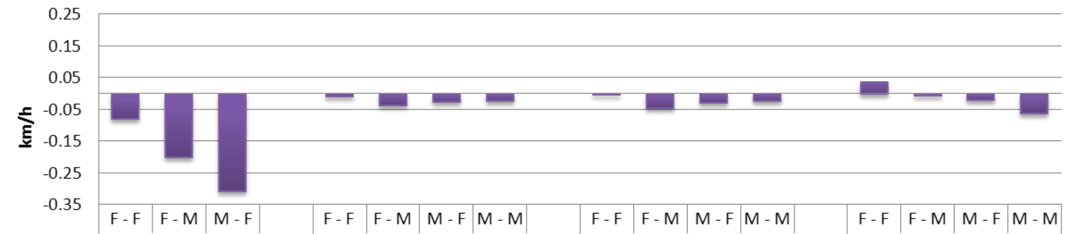
	2006			2007				2008				2009			
	F - F	F - M	M - F	F - F	F - M	M - F	M - M	F - F	F - M	M - F	M - M	F - F	F - M	M - F	M - M
mean speed diff2	0.08	-0.13	0.23	0.05	0.06	0.10	0.06	-0.03	0.11	0.08	0.11	0.04	0.05	0.05	0.05
sample size	1089	82	59	1064	1753	1984	1481	2448	5462	8293	1540	12019	61819	63555	39693
SD speed diff2 *	0.82	1.11	0.63	0.93	0.94	0.84	0.61	0.77	0.76	0.83	1.34	1.21	0.66	0.55	0.55

Mean speed diff2 *72h*



	2006			2007				2008				2009			
	F - F	F - M	M - F	F - F	F - M	M - F	M - M	F - F	F - M	M - F	M - M	F - F	F - M	M - F	M - M
mean speed diff2	0.00	0.16	-0.35	-0.01	-0.08	-0.02	-0.01	-0.04	-0.04	0.00	-0.01	-0.03	0.03	-0.01	-0.02
sample size	545	19	15	1890	1099	1116	1332	2746	2141	2518	1665	8404	10443	10717	7707
SD speed diff2	0.87	0.87	1.36	0.88	0.95	1.47	0.76	0.82	0.96	1.02	1.09	1.15	1.03	0.85	0.98

Mean speed diff2 *168h*

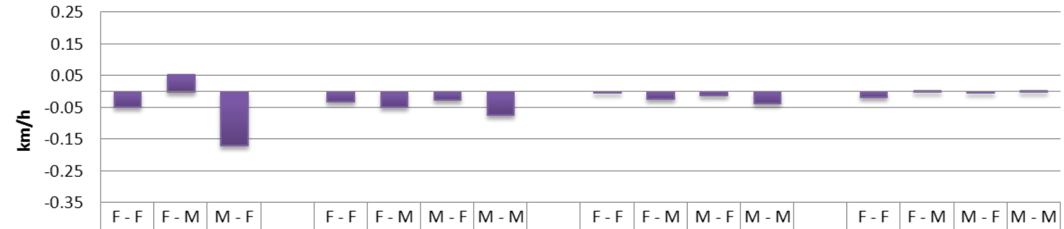


	2006 F - F	2006 F - M	2006 M - F	2007 F - F	2007 F - M	2007 M - F	2007 M - M	2008 F - F	2008 F - M	2008 M - F	2008 M - M	2009 F - F	2009 F - M	2009 M - F	2009 M - M
mean speed diff2	-0.08	-0.20	-0.31	-0.01	-0.04	-0.03	-0.02	0.00	-0.05	-0.03	-0.02	0.04	-0.01	-0.02	-0.06
sample size	1213	73	70	3054	1647	1906	1877	4621	3279	3441	2063	14180	10404	12067	8391
SD speed diff2	1.04	0.97	1.37	0.80	1.03	1.27	0.81	0.79	0.95	1.10	1.22	1.31	1.24	1.17	1.19

Mean speed diff2 *336h*

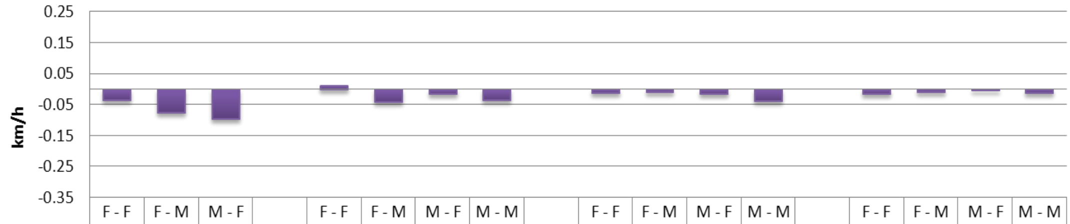
	2006 F - F	2006 F - M	2006 M - F	2007 F - F	2007 F - M	2007 M - F	2007 M - M	2008 F - F	2008 F - M	2008 M - F	2008 M - M	2009 F - F	2009 F - M	2009 M - F	2009 M - M
mean speed diff2	-0.05	-0.06	-0.05	-0.01	-0.03	0.06	-0.05	-0.05	-0.01	-0.03	-0.09	-0.02	-0.06	-0.01	0.00
sample size	1705	55	173	4571	2269	2427	2011	6614	5251	4825	3535	19324	12138	12700	10478
SD speed diff2	1.12	0.99	1.11	0.84	1.01	1.17	0.74	0.83	0.91	1.02	1.18	1.21	1.27	1.31	1.20

Mean speed diff2 *336h+*



	2006 F - F	2006 F - M	2006 M - F	2007 F - F	2007 F - M	2007 M - F	2007 M - M	2008 F - F	2008 F - M	2008 M - F	2008 M - M	2009 F - F	2009 F - M	2009 M - F	2009 M - M
mean speed diff2	-0.05	0.05	-0.17	-0.03	-0.05	-0.03	-0.07	0.00	-0.02	-0.01	-0.04	-0.02	0.00	0.00	0.00
sample size	5002	116	406	12076	5929	7675	4083	18686	19337	9442	11038	57848	39957	34331	35132
SD speed diff2	0.97	0.91	1.19	0.94	1.02	1.73	1.17	0.76	0.81	0.98	1.11	1.21	1.15	1.14	1.19

Mean speed diff2 (total)

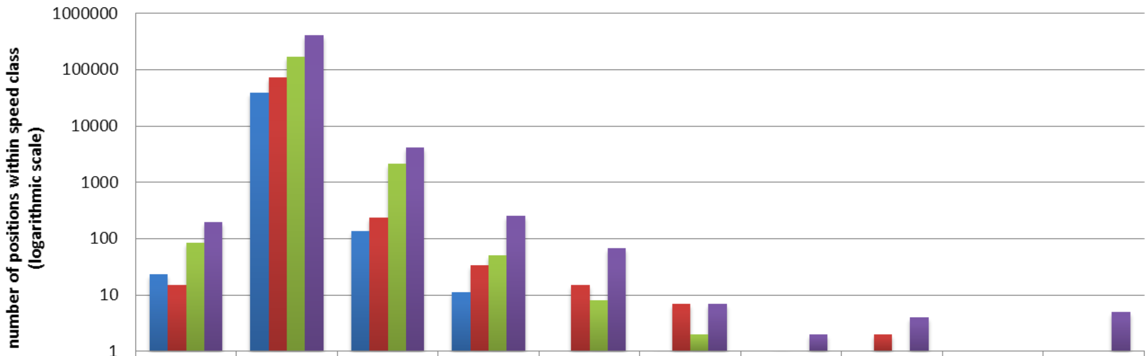


	2006 F - F	2006 F - M	2006 M - F	2007 F - F	2007 F - M	2007 M - F	2007 M - M	2008 F - F	2008 F - M	2008 M - F	2008 M - M	2009 F - F	2009 F - M	2009 M - F	2009 M - M
mean speed diff2	-0.03	-0.08	-0.10	0.01	-0.04	-0.02	-0.04	-0.01	-0.01	-0.02	-0.04	-0.02	-0.01	0.00	-0.01
sample size	9553	534	534	22654	13900	13900	10782	35111	31989	31989	19839	111758	133951	133951	101304
SD speed diff2	1.01	1.11	1.19	0.91	1.01	1.49	0.85	0.84	0.85	1.08	1.15	1.25	0.98	0.95	0.98

Mean speed change averaged over 4 years

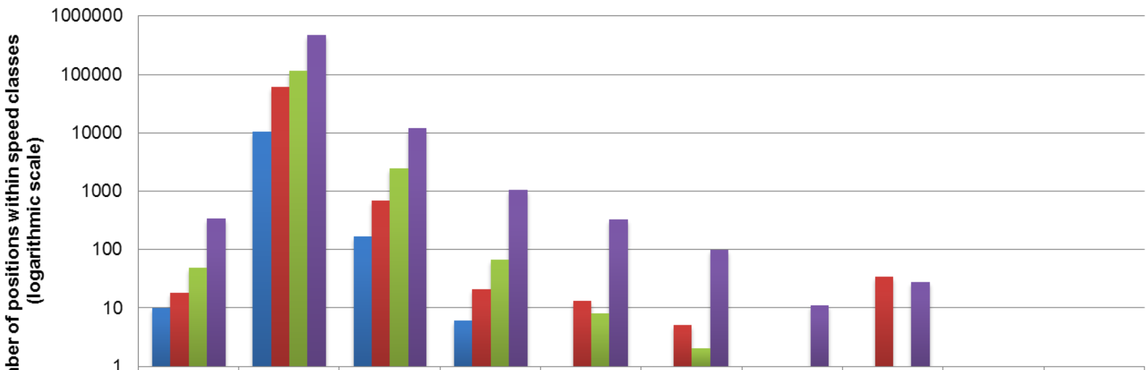
	total 24	total 72	total 168	total 336	total 336+
mean speed diff2	0.06	-0.03	-0.06	-0.03	-0.03
sample size	202341	52357	68286	88076	261058

Frequency distribution of speed classes (all positions)



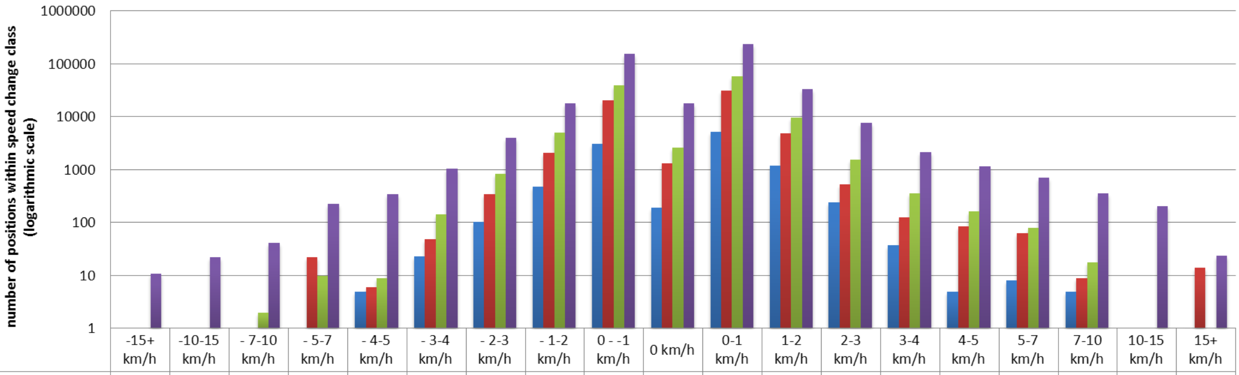
	0 km/h	0-1 km/h	1-2 km/h	2-3 km/h	3-4 km/h	4-5 km/h	5-7 km/h	7-10 km/h	10-15 km/h	15+ km/h
speed_2006	23	38840	133	11	0	1	0	0	0	0
speed_2007	15	71226	237	34	15	7	1	2	0	0
speed_2008	84	165867	2096	50	8	2	0	0	0	0
speed_2009	195	409420	4113	251	67	7	2	4	0	5

Frequency distribution of speed classes *at* intersections



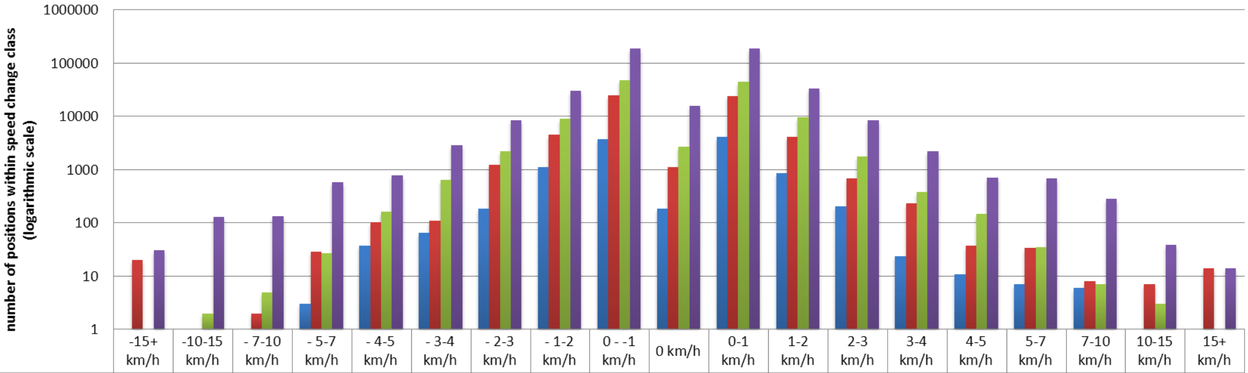
	0 km/h	0-1 km/h	1-2 km/h	2-3 km/h	3-4 km/h	4-5 km/h	5-7 km/h	7-10 km/h	10-15 km/h	15+ km/h
speed_2006	10	10437	168	6	0	1	0	0	0	0
speed_2007	18	60462	691	21	13	5	0	34	0	0
speed_2008	49	116371	2449	66	8	2	0	0	0	0
speed_2009	335	467499	11972	1034	331	97	11	28	0	0

Frequency distribution of speed change classes (speed diff1)



	-15+ km/h	-10-15 km/h	- 7-10 km/h	- 5-7 km/h	- 4-5 km/h	- 3-4 km/h	- 2-3 km/h	- 1-2 km/h	0 - -1 km/h	0 km/h	0-1 km/h	1-2 km/h	2-3 km/h	3-4 km/h	4-5 km/h	5-7 km/h	7-10 km/h	10-15 km/h	15+ km/h
speed_change1_2006	0	0	0	0	5	23	105	481	3124	192	5202	1194	239	38	5	8	5	0	1
speed_change1_2007	0	0	0	22	6	49	346	2073	20497	1300	31300	4816	537	126	85	64	9	0	14
speed_change1_2008	0	0	2	10	9	142	843	5057	39726	2606	58778	9589	1558	362	165	80	18	0	0
speed_change1_2009	11	22	42	223	347	1033	4025	17679	154962	18152	238987	33596	7583	2186	1171	710	352	202	24

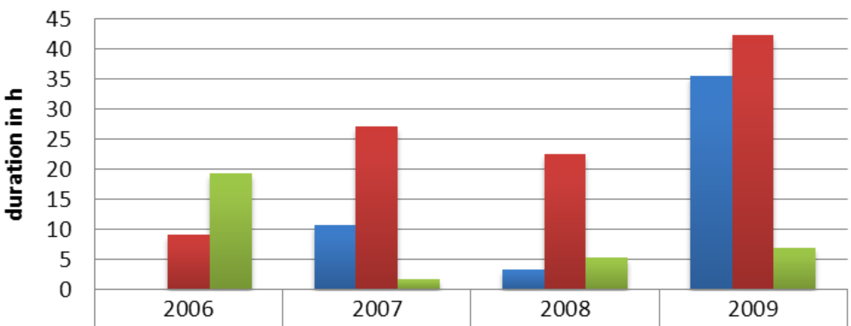
Frequency distribution of speed change classes (speed diff2)



	-15+ km/h	-10-15 km/h	- 7-10 km/h	- 5-7 km/h	- 4-5 km/h	- 3-4 km/h	- 2-3 km/h	- 1-2 km/h	0 - -1 km/h	0 km/h	0-1 km/h	1-2 km/h	2-3 km/h	3-4 km/h	4-5 km/h	5-7 km/h	7-10 km/h	10-15 km/h	15+ km/h
speed_change2_2006	0	0	0	3	37	66	187	1123	3799	188	4095	869	207	24	11	7	6	0	0
speed_change2_2007	20	0	2	29	102	112	1241	4550	24979	1105	23986	4103	677	237	38	34	8	7	14
speed_change2_2008	0	2	5	27	162	645	2196	9086	47074	2663	45115	9631	1761	383	150	35	7	3	0
speed_change2_2009	31	131	136	582	786	2901	8583	30108	190333	15543	186510	33254	8450	2239	707	676	284	39	14

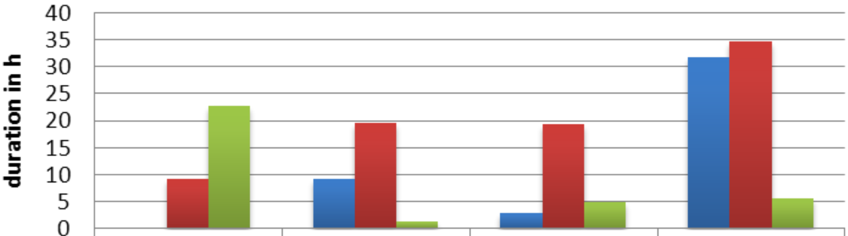
RQ 2 – encounters

Mean encounter duration according to sex (100m)



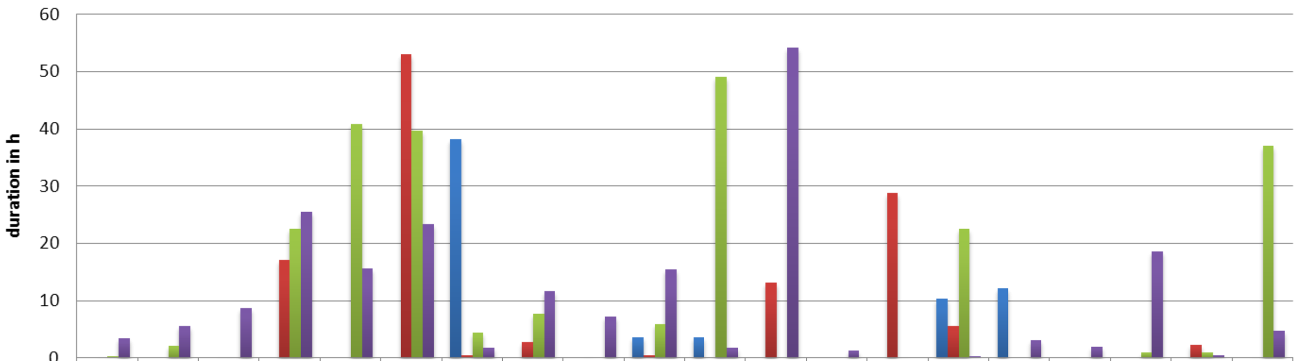
	2006	2007	2008	2009
M-M		10.8	3.39	35.58
M-F	9.16	27.12	22.59	42.45
F-F	19.41	1.68	5.4	6.88

Mean encounter duration according to sex (200m)



	2006	2007	2008	2009
M-M		9.21	3.02	31.8
M-F	9.16	19.64	19.34	34.64
F-F	22.76	1.41	4.87	5.65

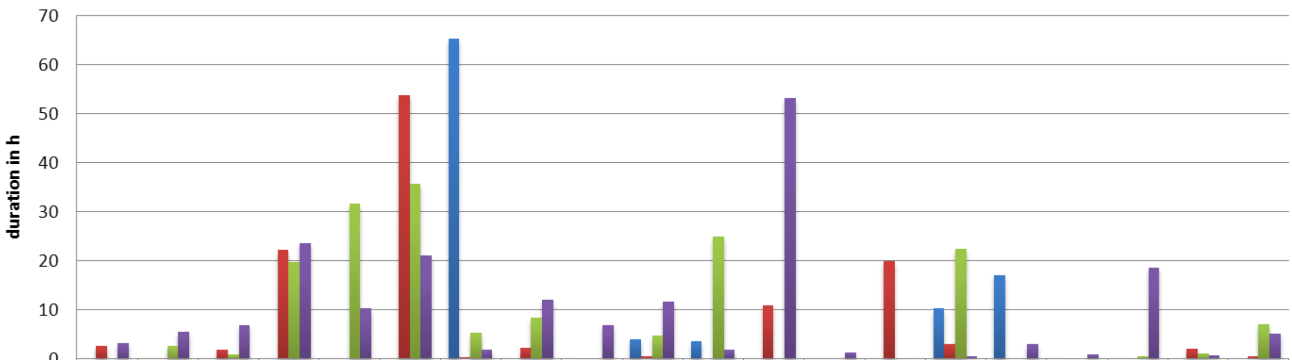
Mean encounter duration (h) according to RS (100m)



	AM - SAM	AM - AM	AM - SAF	AM - RF	AM - COY	AM - YL	RF - SAF	RF - RF	RF - COY	RF - YL	RF - SAM	SAM - SAM	SAM - COY	SAM - YL	SAF - SAM	SAF - SAF	SAF - COY	COY - YL	SAF - YL	no data
2006							38.17			3.56	3.53				10.29	12.05				
2007	0		0	17.05		52.91	0.49	2.71	0	0.37	0	13.11		28.82	5.48		0.17		2.31	0
2008	0.18	2.13	0	22.51	40.84	39.57	4.44	7.68		5.81	49.01			0	22.5			1	1	37
2009	3.46	5.51	8.66	25.54	15.51	23.33	1.81	11.63	7.24	15.4	1.73	54.2	1.21		0.26	3.14	1.84	18.5	0.49	4.74

Note: one outlier has been removed in this graph (2009, SAM-YL, 420.38h)

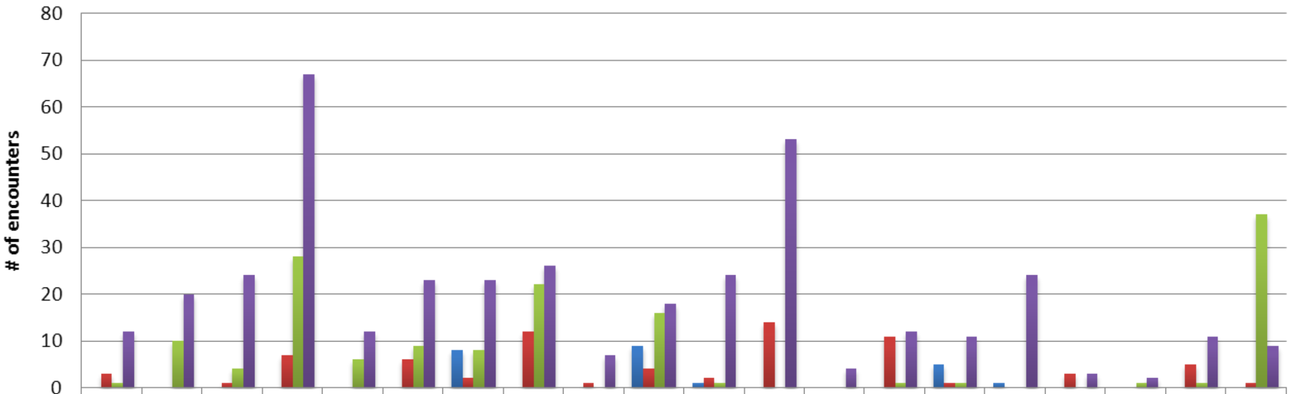
Mean encounter duration (h) according to RS (200m)



	AM - SAM	AM - AM	AM - SAF	AM - RF	AM - COY	AM - YL	RF - SAF	RF - RF	RF - COY	RF - YL	RF - SAM	SAM - SAM	SAM - COY	SAM - YL	SAF - SAM	SAF - SAF	SAF - COY	COY - YL	SAF - YL	no data
2006							65.18			4	3.53				10.29	16.99				
2007	2.7		1.83	22.31		53.74	0.33	2.29	0	0.5	0.07	10.92		19.84	2.99		0.13		2.08	0.5
2008	0.17	2.57	0.83	19.76	31.61	35.7	5.25	8.45	0	4.71	25			0	22.5			0.5	0.99	7.02
2009	3.18	5.52	6.87	23.56	10.35	21.02	1.77	11.99	6.82	11.62	1.82	53.24	1.21		0.47	3.04	0.95	18.5	0.65	5.15

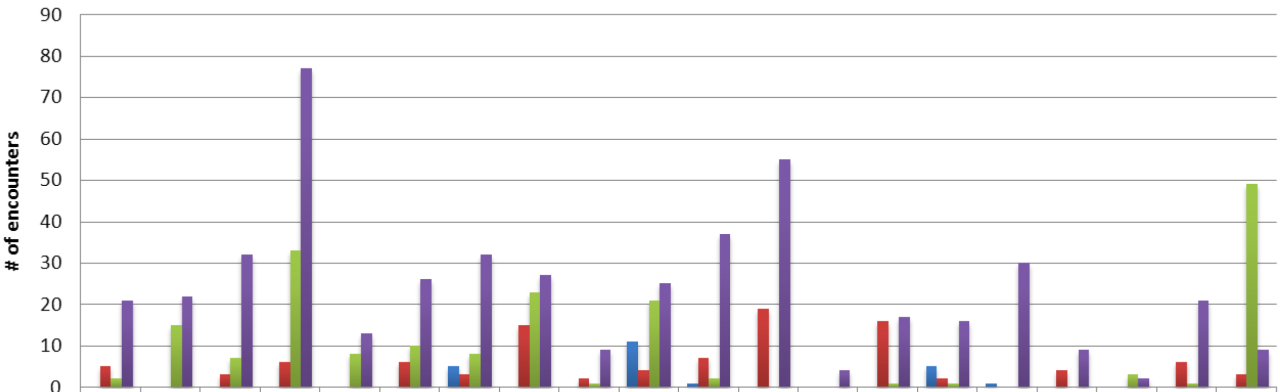
Note: one outlier has been removed in this graph (2009, SAM-YL, 298h)

numbers of encounters according to RS (100m)



	AM - SAM	AM - AM	AM - SAF	AM - RF	AM - COY	AM - YL	RF - SAF	RF - RF	RF - COY	RF - YL	RF - SAM	SAM - SAM	SAM - COY	SAM - YL	SAF - SAM	SAF - SAF	SAF - COY	COY - YL	SAF - YL	no data
2006							8			9	1				5	1				
2007	3		1	7		6	2	12	1	4	2	14		11	1		3		5	1
2008	1	10	4	28	6	9	8	22		16	1			1	1			1	1	37
2009	12	20	24	67	12	23	23	26	7	18	24	53	4	12	11	24	3	2	11	9

numbers of encounters according to RS (200m)



	AM - SAM	AM - AM	AM - SAF	AM - RF	AM - COY	AM - YL	RF - SAF	RF - RF	RF - COY	RF - YL	RF - SAM	SAM - SAM	SAM - COY	SAM - YL	SAF - SAM	SAF - SAF	SAF - COY	COY - YL	SAF - YL	no data
2006							5			11	1				5	1				
2007	5		3	6		6	3	15	2	4	7	19		16	2		4		6	3
2008	2	15	7	33	8	10	8	23	1	21	2			1	1			3	1	49
2009	21	22	32	77	13	26	32	27	9	25	37	55	4	17	16	30	9	2	21	9

Spatio-temporal analysis of brown bear interactions

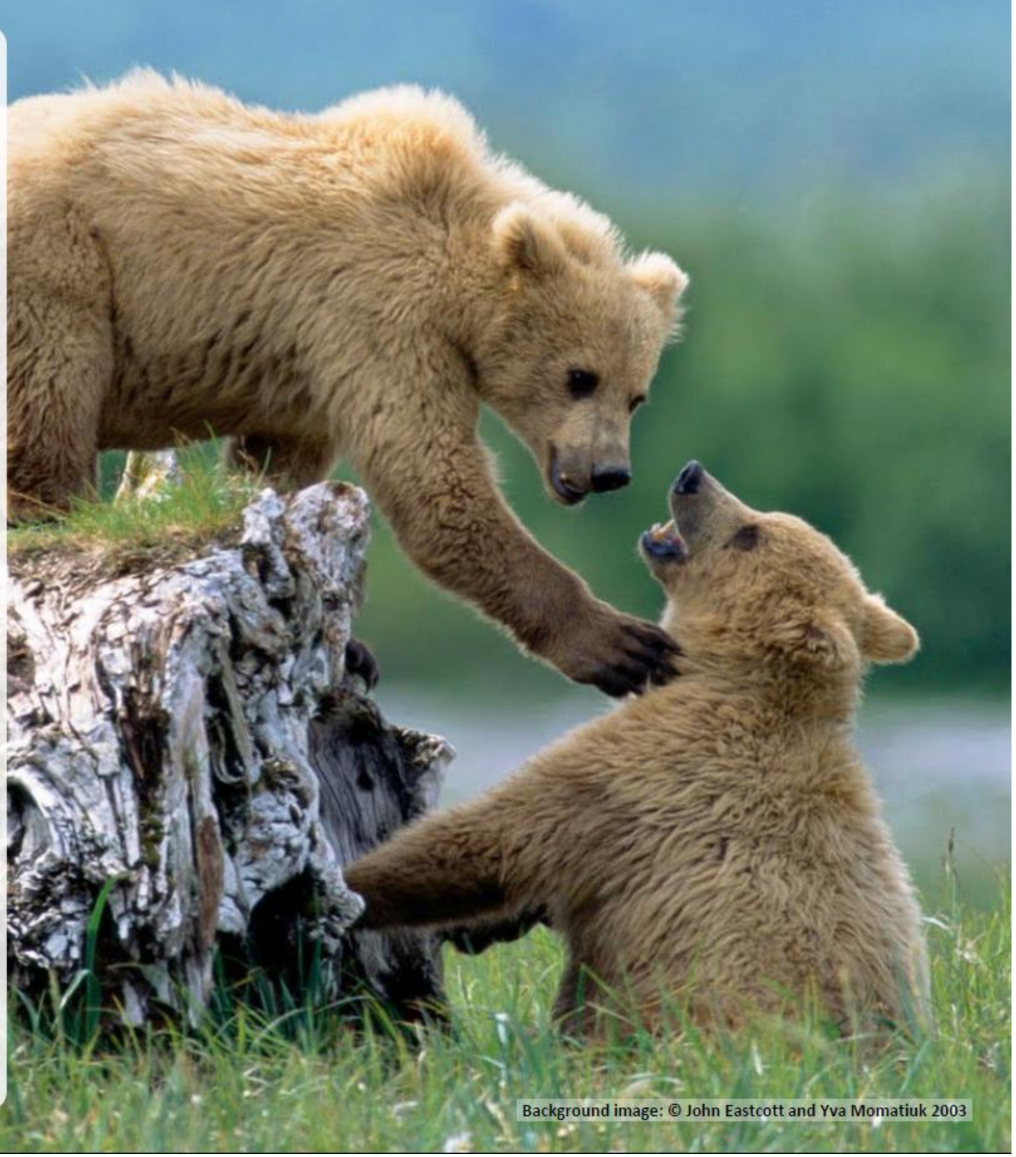
INTRODUCTION

This information leaflet presents a short summary of the thesis work with the title "**Analysis of brown bear (*Ursus arctos*) interactions in the mating season by applying spatio-temporal concepts in GIS**". It depicts a simple overview about the applied methodologies and how results were obtained. Moreover, the results themselves are described for validation by bear specialists (you).

The bears which are tracked by the Scandinavian Brown Bear Research Project (SBBRP) produce vast amounts of movement data. The recorded trajectories not only contain spatial data, but also temporal information. In order to extract information about specific behaviour of the tracked bears, this data can be used for spatio-temporal analysis in a Geographic Information System (GIS). The objective of this thesis was to develop the methods which are required for implementing such concepts in a GIS in order to create and extract new information. This means that certain spatio-temporal concepts have to be applied in order to find specific patterns in the data. Such concepts can be basic/low level ones like position, time, speed, direction or change in one of those. More advanced concepts are for example co-incidence in space or time or lagged co-incidence (Andrienko et al., 2008; Andrienko and Andrienko, 2007). These concepts have been applied to answer the following research questions:

- **RQ 1: Can changes in speed and direction be observed after an individual crosses the path of another one?**
- **RQ 2: How long do encounters between individuals last?**

On the following pages you will get an overview of the general analysis as well as the specific methods applied for answering the research questions. Also results and questions will be presented according to each research question. Your answers to these questions will serve as validation of the research I conducted.

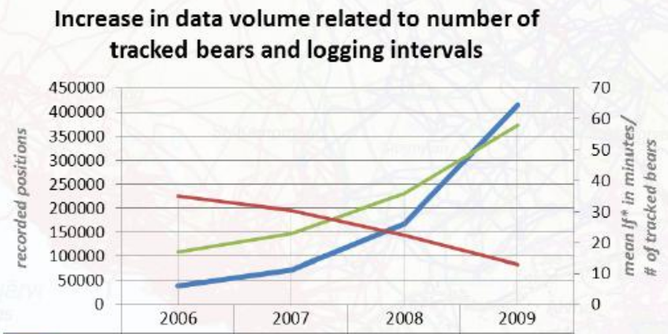


Background image: © John Eastcott and Yva Momatiuk 2003

DATA & PRE-PROCESSING

For this research, tracking data from the southern study area for the years 2006 to 2009 was available. Only positions for the mating season from May to mid-July (Dahle & Swenson, 2003; Støen et al., 2006; Swenson et al., 1997) were analysed, which still meant vast amounts of data (Figure 1). For efficient processing of these big amounts of data, proper pre-processing of the data was necessary. The pre-processing is one of three main parts of this study as shown in Figure 2. It includes the import of the movement data into ArcGIS, the removal of non-required attributes and the adding of demographic information like reproductive status to the spatial data. Furthermore, additional variables like *steplength (step)*, *bearing*, *turnangle* (spatial), *steptime* and *speed* (temporal) are calculated and added (Figure 3). These will be required in the two remaining parts, which concern the analysis for the respective research questions.

All analysis has been conducted using ArcGIS 9.3 with ArcInfo License. During pre-processing of the data, Hawth's Tools V 3.27 has been used for some operations. Many processing steps were conducted by the use of Python scripting, which is required in order to batch and improve ArcGIS functionality.



	2006	2007	2008	2009
positions	39025	71560	168143	414400
bears	17	23	36	58
mean lf*	34.9	30.3	22.5	12.8

* mean logging frequency in minutes

Figure 1 Number of recorded positions used for the analysis (blue graph) for the years 2006-2009. Furthermore, the numbers of tracked bears for each year (green graph) and the mean logging frequencies per year (red graph) are shown.

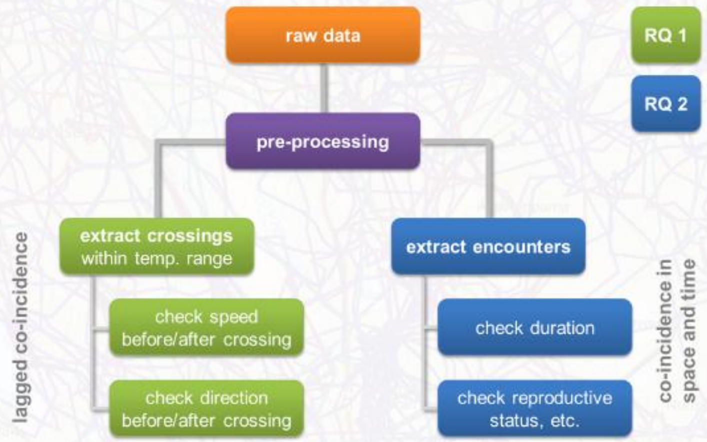


Figure 2 Schematic representation of analysis processes.

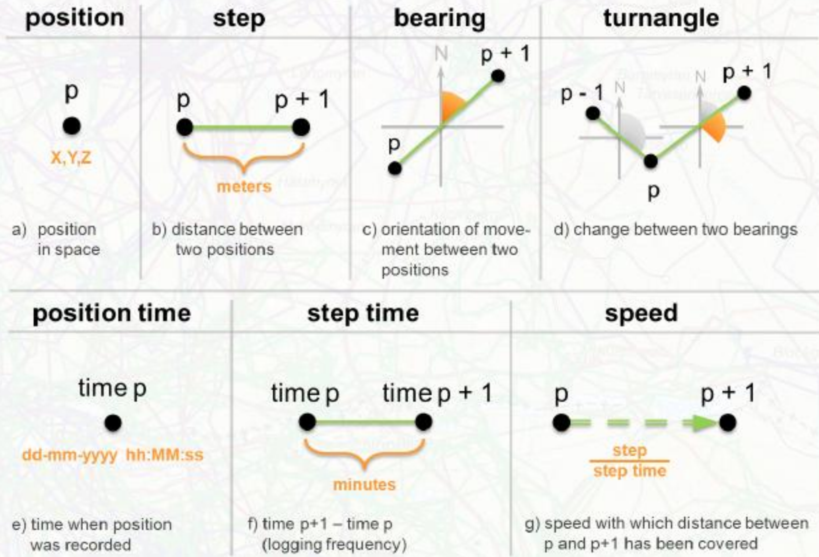


Figure 3 Spatial (top row) and temporal (bottom row) variables created in pre-processing and applied

Background: extract from 2009 positions

METHODS RQ 1

This research question is based on the spatio-temporal concept of **lagged co-incidence** (Andrienko et al., 2008; Andrienko and Andrienko, 2007). This means that two positions are at the same spatial location, but not at the same time. This corresponds to the case when one bear crosses the track of another bear.

The way of extracting these positions is by intersecting tracks with each other. During the pre-processing, a track dataset for each individual bear has been created, meaning that positions (points) have been converted to continuous line datasets. These line datasets can be intersected with each other (each individual with all other individuals; all intersections within breeding season; Figure 4 ①). The resulting intersect datasets depict bears crossing the tracks of other bears. In the next two steps, the speeds before and after the crossing are extracted and the differences in speeds are calculated (Figure 4 ② and ③). The differences in speed have been calculated between **a)** the step before the intersect (S1) and the step at the intersect (S2) (*speedDiff1*) and **b)** between the step before the intersect (S1) and the step after the intersect (S3) (*speedDiff2*) (Figure 5). The change in direction (turnangle, see chapter *'Data & pre-processing'*) was only calculated between steps S1 and S2.

At this moment the values for changes in speed and direction are already available, the following two steps (Figure 4 ④ and ⑤) will now extract datasets according to different conditions. First of all, intersects are selected according to how old the crossed path is (0-24h, 24-72h, 72-168h, 168-336h, >336h). That is supposed to give an idea of different reactions when crossing tracks of different ages.

The following selection further splits the datasets up according to the sex of the individuals (male crossed a track of a male, male crossed a track of a female, etc.).

Figure 4 Simplified methodology RQ 1.

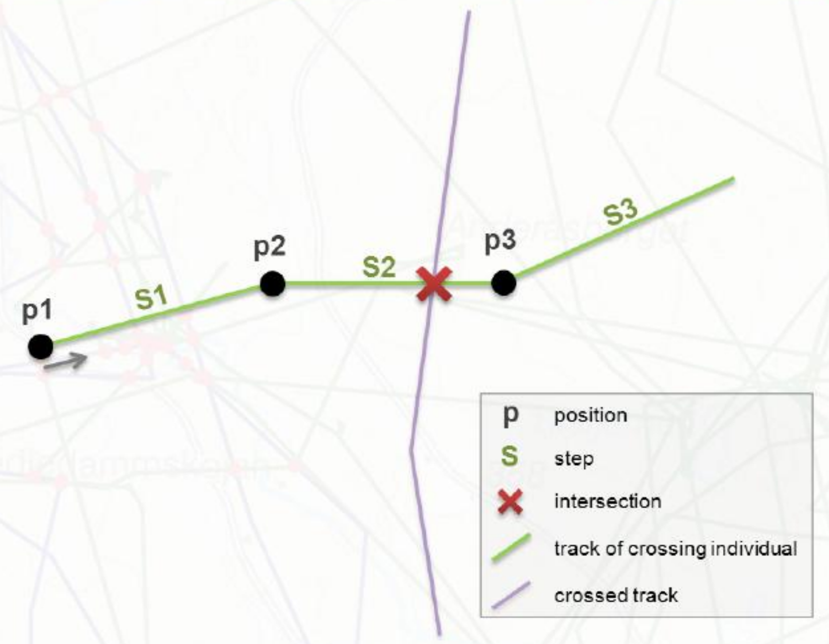


Figure 5 One individual crosses the track of another individual. A step always inherits the values (i.e. time) of the previous position (i.e. S1 has the same time value as p1).

Background: intersects W0004 with W0010 (2006)

METHODS RQ 2

This research question is based on the spatio-temporal concept **co-incidence in space and time** (Andrienko et al., 2008; Andrienko and Andrienko, 2007), implying positions are at the same spatial location at the same time. As positions with exactly equal values in time and space do not occur in reality, thresholds (buffers), both in space and time are applied. This means that positions within a spatial distance of 100 meters or 200 meters around a position respectively, and within a temporal distance of +/- 15 minutes are considered to meet the criteria for an encounter (Figure 6). The two different spatial distances are applied in order to see, what influence on the end results this will have.

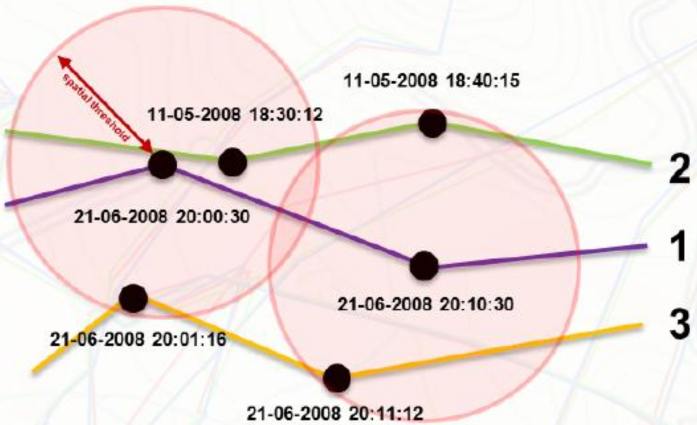


Figure 6 This figure shows the encounters for individual '1'. It can be observed that positions of individual '2' and '3' are within the defined spatial threshold of individual '1', but only positions of individual '3' are also within the temporal threshold. This indicates that individuals '1' and '3' have actually met in this example, but not individual '1' and '2'.

The first two processing steps (Figure 7 ① and ②) are implemented within one script, which extracts all positions which apply to the mentioned conditions. First it selects all positions that are within the defined spatial distance (e.g. 100m) to other positions. The second part of this script then only extracts positions which are also within the temporal distance (+/- 15 minutes).

In the next processing step, all these encounter positions will be grouped together to so-called *coherent encounters* (Figure 7 ③). A coherent encounter is a pair of positions of two individuals, or a series of pairs of positions of two individuals. The time difference between the positions (per individual, not with each other—this is still +/- 15 min) within the spatial distance may not be bigger than a certain threshold (in this case 5 hours). This threshold is required because positions can be either out of the spatial threshold (but there still is an encounter) or positions are not recorded at the specified logging interval (because of technical issues from the GPS). This assures that if for example an encounter is extracted, but within some positions there is a time lag of 2 days, this will be regarded as two and not one coherent encounter.

The next process calculates the duration for each coherent encounter (Figure 7 ④). In a last step, the durations will be extracted according to sex and reproductive status combinations (Figure 7 ⑤).

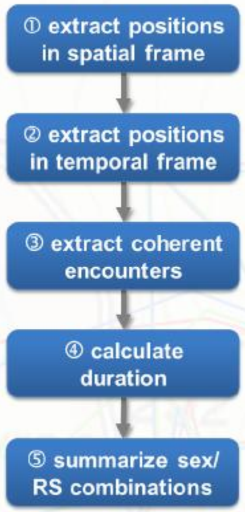


Figure 7 Simplified methodology RQ 2.

Background: mother (W0104) with cubs (W0901, W0902)

RESULTS RQ 1 - CHANGE IN DIRECTION

As follows, results of research question 1 regarding change in direction are presented. The graphs show the change in direction according to different sex combinations (e.g. male crossed the track of a female) for each year. Every graph represents a specific age of the crossed track (was the crossed track fresher or older):

- 0-24h
- 24-72h
- 72-168h
- 168-336h
- > 336h

All data/graphs are also available for combinations of reproductive status, but have not been included here for better overview.

Mean turnangle *24h*

	2006 F - F	2006 F - M	2006 M - F		2007 F - F	2007 F - M	2007 M - F	2007 M - M	2008 F - F	2008 F - M	2008 M - F	2008 M - M	2009 F - F	2009 F - M	2009 M - F	2009 M - M
mean turnangle	-1.04	12.64	19.93		3.34	-1.11	-8.32	4.69	-0.99	1.97	1.51	0.72	7.75	-2.04	-3.15	0.36
sample size	1089	82	59		1064	1753	1984	1481	2448	5462	8293	1540	12019	61819	63555	39693
SD* turnangle	108.42	79.74	103.47		85.72	110.05	105.27	113.93	97.93	114.78	114.18	89.84	104.25	121.70	122.33	119.01

* standard deviation

Mean turnangle *72h*

	2006 F - F	2006 F - M	2006 M - F		2007 F - F	2007 F - M	2007 M - F	2007 M - M	2008 F - F	2008 F - M	2008 M - F	2008 M - M	2009 F - F	2009 F - M	2009 M - F	2009 M - M
mean turnangle	2.51	-20.75	-14.88		6.19	3.21	1.90	2.75	2.08	5.74	9.47	2.61	-0.60	-3.47	-10.37	0.00
sample size	545	19	15		1890	1099	1116	1332	2746	2141	2518	1665	8404	10443	10717	7707
SD turnangle	82.12	71.95	71.53		80.12	84.04	90.63	103.25	81.33	83.45	90.77	91.64	78.66	101.20	107.29	100.63

Mean turnangle *168h*

	2006 F - F	2006 F - M	2006 M - F		2007 F - F	2007 F - M	2007 M - F	2007 M - M	2008 F - F	2008 F - M	2008 M - F	2008 M - M	2009 F - F	2009 F - M	2009 M - F	2009 M - M
mean turnangle	10.48	2.87	10.20		2.33	0.18	2.18	2.86	-1.55	0.76	-2.15	-3.37	0.14	0.43	-3.01	-2.85
sample size	1213	73	70		3054	1647	1906	1877	4621	3279	3441	2063	14180	10404	12067	8391
SD turnangle	80.18	61.28	65.27		81.79	75.57	86.87	99.63	75.20	77.04	78.83	88.00	80.56	82.72	94.99	83.35

Mean turnangle *336h*

	2006 F - F	2006 F - M	2006 M - F		2007 F - F	2007 F - M	2007 M - F	2007 M - M	2008 F - F	2008 F - M	2008 M - F	2008 M - M	2009 F - F	2009 F - M	2009 M - F	2009 M - M
mean turnangle	3.49	1.80	13.58		-0.43	-0.09	1.89	5.61	-0.54	1.45	0.07	3.03	3.78	-0.40	0.22	-3.15
sample size	1705	55	173		4571	2269	2427	2011	6614	5251	4825	3535	19324	12138	12700	10478
SD turnangle	76.02	61.23	69.67		77.20	74.30	81.75	99.81	72.20	70.27	74.46	80.11	76.27	70.52	79.52	82.72

Mean turnangle *336h+*

	2006 F - F	2006 F - M	2006 M - F		2007 F - F	2007 F - M	2007 M - F	2007 M - M	2008 F - F	2008 F - M	2008 M - F	2008 M - M	2009 F - F	2009 F - M	2009 M - F	2009 M - M
mean turnangle	3.74	1.66	1.72		2.12	6.73	1.92	3.75	-0.47	0.62	1.02	4.52	0.98	1.43	-1.07	-0.94
sample size	5002	116	406		12076	5929	7675	4083	18686	19337	9442	11038	57848	39957	34331	35132
SD turnangle	78.05	71.70	63.33		73.03	70.56	82.52	96.25	71.84	71.64	65.98	85.76	74.27	71.13	73.05	76.57

Mean turnangle (total)

	2006 F - F	2006 F - M	2006 M - F		2007 F - F	2007 F - M	2007 M - F	2007 M - M	2008 F - F	2008 F - M	2008 M - F	2008 M - M	2009 F - F	2009 F - M	2009 M - F	2009 M - M
mean turnangle	2.38	1.25	3.38		2.17	3.00	0.33	1.11	-0.51	0.96	0.33	2.70	1.18	-0.90	-1.64	-0.70
sample size	9553	534	534		22654	13900	13900	10782	35111	31989	31989	19839	111758	133951	133951	101304
SD turnangle	83.48	74.51	71.41		75.87	80.57	84.49	100.17	76.41	85.73	84.86	86.74	80.15	101.98	103.17	98.90

Mean turnangle averaged over 4 years

	total 24	total 72	total 168	total 336	total 336+
mean turnangle	2.42	-0.91	1.30	2.02	1.85
sample size	202341	52357	68286	88076	261058

RESULTS RQ 1 - CHANGE IN SPEED 1

The following two pages present the results of research question 1 regarding the changes in speed after the crossing of a track of another bear. The graphs on this page show the differences in speed between the step *before* and the step *at* the intersection (see Figure 5). The graphs on the next page show the differences in speed between the step *before* and the step *after* the intersection (see again Figure 5). The results on this page do not show big changes in speed (maximum + 0.39 km/h), but it is striking that (almost) all changes are positive (increase in speed).

Mean speed diff1 *24h*

	2006 F-F	2006 F-M	2006 M-F	2007 F-F	2007 F-M	2007 M-F	2007 M-M	2008 F-F	2008 F-M	2008 M-F	2008 M-M	2009 F-F	2009 F-M	2009 M-F	2009 M-M
mean speed diff1	0.15	0.12	0.39	0.08	0.13	0.15	0.17	0.07	0.15	0.14	0.23	0.15	0.07	0.07	0.08
sample size	1089	82	59	1064	1753	1984	1481	2448	5462	8293	1540	12019	61819	63555	39693
SD speed diff1 *	0.75	0.86	0.76	0.75	0.75	0.66	0.52	0.68	0.64	0.78	1.08	1.01	0.52	0.45	0.46

* standard deviation

Mean speed diff1 *72h*

	2006 F-F	2006 F-M	2006 M-F	2007 F-F	2007 F-M	2007 M-F	2007 M-M	2008 F-F	2008 F-M	2008 M-F	2008 M-M	2009 F-F	2009 F-M	2009 M-F	2009 M-M
mean speed diff1	0.25	0.45	0.02	0.12	0.13	0.18	0.19	0.09	0.15	0.07	0.14	0.15	0.12	0.11	0.13
sample size	545	19	15	1890	1099	1116	1332	2746	2141	2518	1665	8404	10443	10717	7707
SD speed diff1	0.79	0.93	0.93	0.71	0.79	1.08	0.61	0.68	0.84	0.88	0.85	1.02	0.91	0.75	0.80

Mean speed diff1 *168h*

	2006 F-F	2006 F-M	2006 M-F	2007 F-F	2007 F-M	2007 M-F	2007 M-M	2008 F-F	2008 F-M	2008 M-F	2008 M-M	2009 F-F	2009 F-M	2009 M-F	2009 M-M
mean speed diff1	0.11	-0.09	0.10	0.17	0.14	0.21	0.18	0.15	0.13	0.14	0.15	0.22	0.19	0.11	0.14
sample size	1213	73	70	3054	1647	1906	1877	4621	3279	3441	2063	14180	10404	12067	8391
SD speed diff1	0.81	0.62	0.91	0.76	0.87	0.92	0.62	0.70	0.77	0.93	0.99	1.09	1.11	0.93	0.96

Mean speed diff1 *336h*

	2006 F-F	2006 F-M	2006 M-F	2007 F-F	2007 F-M	2007 M-F	2007 M-M	2008 F-F	2008 F-M	2008 M-F	2008 M-M	2009 F-F	2009 F-M	2009 M-F	2009 M-M
mean speed diff1	0.22	0.25	0.25	0.12	0.18	0.20	0.16	0.15	0.17	0.15	0.09	0.23	0.23	0.20	0.20
sample size	1705	55	173	4571	2269	2427	2011	6614	5251	4825	3535	19324	12138	12700	10478
SD speed diff1	0.98	0.76	0.86	0.80	0.89	0.88	0.60	0.72	0.75	0.85	0.93	1.07	1.19	1.13	1.08

Mean speed diff1 *336h+*

	2006 F-F	2006 F-M	2006 M-F	2007 F-F	2007 F-M	2007 M-F	2007 M-M	2008 F-F	2008 F-M	2008 M-F	2008 M-M	2009 F-F	2009 F-M	2009 M-F	2009 M-M
mean speed diff1	0.23	0.20	0.11	0.17	0.19	0.25	0.18	0.17	0.17	0.16	0.17	0.25	0.22	0.21	0.22
sample size	5002	116	406	12076	5929	7675	4083	18686	19337	9442	11038	57848	39957	34331	35132
SD speed diff1	0.81	0.66	0.84	0.81	0.87	1.17	0.75	0.64	0.72	0.81	0.87	1.17	1.06	1.00	1.04

Mean speed diff1 (total)

	2006 F-F	2006 F-M	2006 M-F	2007 F-F	2007 F-M	2007 M-F	2007 M-M	2008 F-F	2008 F-M	2008 M-F	2008 M-M	2009 F-F	2009 F-M	2009 M-F	2009 M-M
mean speed diff1	0.22	0.19	0.17	0.16	0.16	0.21	0.16	0.17	0.15	0.17	0.18	0.24	0.13	0.13	0.15
sample size	9553	534	534	22654	13900	13900	10782	35111	31989	31989	19839	111758	133951	133951	101304
SD speed diff1	0.85	0.92	0.85	0.78	0.84	1.09	0.62	0.71	0.74	0.91	0.92	1.12	0.86	0.81	0.84

Mean speed change averaged over 4 years

	total 24	total 72	total 168	total 336	total 336+
mean speed diff1	0.14	0.15	0.14	0.19	0.19
sample size	202341	52357	68286	88076	261058

RESULTS RQ 1 - CHANGE IN SPEED 2

This page shows the differences in speed between the step *before* and the step *after* the intersection (see Figure 5). Compared to the results presented on the previous page, the changes in speed are smaller, the trend goes to a slight reduction of speed instead of an increase.

The top speed of a brown bear has been assumed to be around 56 km/h (35 mp/h) (which may be too high, but does not influence the results in this case). Calculated speeds in the datasets can have higher values than that, which is probably caused by GPS inaccuracies. All values higher than the assumed maximum speed have been excluded in this analysis.

Mean speed diff2 *24h*

	2006 F-F	2006 F-M	2006 M-F	2007 F-F	2007 F-M	2007 M-F	2007 M-M	2008 F-F	2008 F-M	2008 M-F	2008 M-M	2009 F-F	2009 F-M	2009 M-F	2009 M-M
mean speed diff2	0.08	-0.13	0.23	0.05	0.06	0.10	0.06	-0.03	0.11	0.08	0.11	0.04	0.05	0.05	0.05
sample size	1089	82	59	1064	1753	1984	1481	2448	5462	8293	1540	12019	61819	63555	39693
SD speed diff2 *	0.82	1.11	0.63	0.93	0.94	0.84	0.61	0.77	0.76	0.83	1.34	1.21	0.66	0.55	0.55

* standard deviation

Mean speed diff2 *72h*

	2006 F-F	2006 F-M	2006 M-F	2007 F-F	2007 F-M	2007 M-F	2007 M-M	2008 F-F	2008 F-M	2008 M-F	2008 M-M	2009 F-F	2009 F-M	2009 M-F	2009 M-M
mean speed diff2	0.00	0.16	-0.35	-0.01	-0.08	-0.02	-0.01	-0.04	-0.04	0.00	-0.01	-0.03	0.03	-0.01	-0.02
sample size	545	19	15	1890	1099	1116	1332	2746	2141	2518	1665	8404	10443	10717	7707
SD speed diff2	0.87	0.87	1.36	0.88	0.95	1.47	0.76	0.82	0.96	1.02	1.09	1.15	1.03	0.85	0.98

Mean speed diff2 *168h*

	2006 F-F	2006 F-M	2006 M-F	2007 F-F	2007 F-M	2007 M-F	2007 M-M	2008 F-F	2008 F-M	2008 M-F	2008 M-M	2009 F-F	2009 F-M	2009 M-F	2009 M-M
mean speed diff2	-0.08	-0.20	-0.31	-0.01	-0.04	-0.03	-0.02	0.00	-0.05	-0.03	-0.02	0.04	-0.01	-0.02	-0.06
sample size	1213	73	70	3054	1647	1906	1877	4621	3279	3441	2063	14180	10404	12067	8391
SD speed diff2	1.04	0.97	1.37	0.80	1.03	1.27	0.81	0.79	0.95	1.10	1.22	1.31	1.24	1.17	1.19

Mean speed diff2 *336h*

	2006 F-F	2006 F-M	2006 M-F	2007 F-F	2007 F-M	2007 M-F	2007 M-M	2008 F-F	2008 F-M	2008 M-F	2008 M-M	2009 F-F	2009 F-M	2009 M-F	2009 M-M
mean speed diff2	-0.05	-0.06	-0.05	-0.01	-0.03	0.06	-0.05	-0.05	-0.01	-0.03	-0.09	-0.02	-0.06	-0.01	0.00
sample size	1705	55	173	4571	2269	2427	2011	6614	5251	4825	3535	19324	12138	12700	10478
SD speed diff2	1.12	0.99	1.11	0.84	1.01	1.17	0.74	0.83	0.91	1.02	1.18	1.21	1.27	1.31	1.20

Mean speed diff2 *336h+*

	2006 F-F	2006 F-M	2006 M-F	2007 F-F	2007 F-M	2007 M-F	2007 M-M	2008 F-F	2008 F-M	2008 M-F	2008 M-M	2009 F-F	2009 F-M	2009 M-F	2009 M-M
mean speed diff2	-0.05	0.05	-0.17	-0.03	-0.05	-0.03	-0.07	0.00	-0.02	-0.01	-0.04	-0.02	0.00	0.00	0.00
sample size	5002	116	406	12076	5929	7675	4083	18686	19337	9442	11038	57848	39957	34331	35132
SD speed diff2	0.97	0.91	1.19	0.94	1.02	1.73	1.17	0.76	0.81	0.98	1.11	1.21	1.15	1.14	1.19

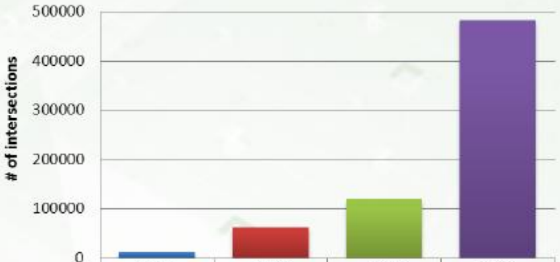
Mean speed diff2 (total)

	2006 F-F	2006 F-M	2006 M-F	2007 F-F	2007 F-M	2007 M-F	2007 M-M	2008 F-F	2008 F-M	2008 M-F	2008 M-M	2009 F-F	2009 F-M	2009 M-F	2009 M-M
mean speed diff2	-0.03	-0.08	-0.10	0.01	-0.04	-0.02	-0.04	-0.01	-0.01	-0.02	-0.04	-0.02	-0.01	0.00	-0.01
sample size	9553	534	534	22654	13900	13900	10782	35111	31989	31989	19839	111758	133951	133951	101304
SD speed diff2	1.01	1.11	1.19	0.91	1.01	1.49	0.85	0.84	0.85	1.08	1.15	1.25	0.98	0.95	0.98

Mean speed change averaged over 4 years

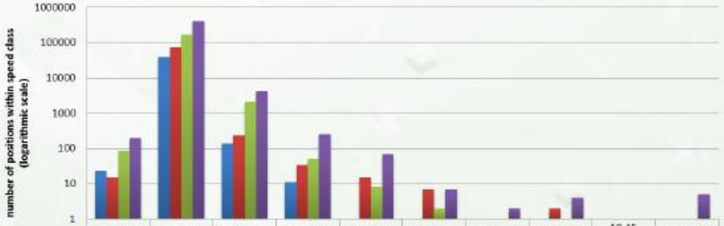
	total 24	total 72	total 168	total 336	total 336+
mean speed diff2	0.06	-0.03	-0.06	-0.03	-0.03
sample size	202341	52357	68286	88076	261058

Total number of intersections analysed



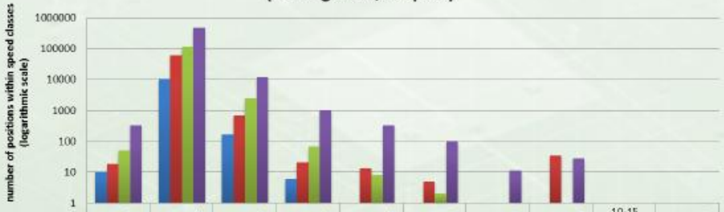
	2006	2007	2008	2009
intersections	10622	61244	118945	481307

Frequency distribution of speed classes (all positions)



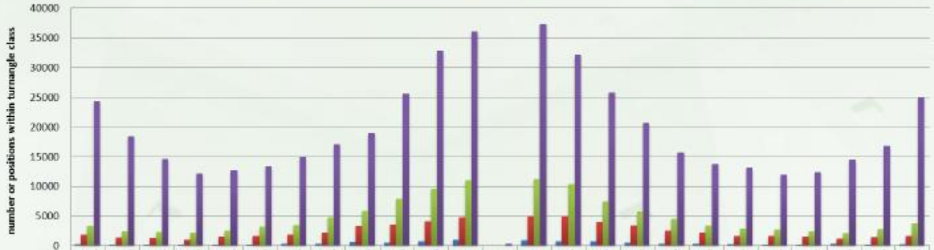
	0 km/h	0-1 km/h	1-2 km/h	2-3 km/h	3-4 km/h	4-5 km/h	5-7 km/h	7-10 km/h	10-15 km/h	15+ km/h
speed_2006	23	38840	133	11	0	1	0	0	0	0
speed_2007	15	71226	237	34	15	7	1	2	0	0
speed_2008	84	165867	2096	50	8	2	0	0	0	0
speed_2009	195	409420	4113	251	67	7	2	4	0	5

Frequency distribution of speed classes *at* intersections (see Figure 5, step S2)



	0 km/h	0-1 km/h	1-2 km/h	2-3 km/h	3-4 km/h	4-5 km/h	5-7 km/h	7-10 km/h	10-15 km/h	15+ km/h
speed_2006	10	10437	168	6	0	1	0	0	0	0
speed_2007	18	60462	691	21	13	5	0	34	0	0
speed_2008	49	116371	2449	66	8	2	0	0	0	0
speed_2009	335	467499	11972	1034	331	97	11	28	0	0

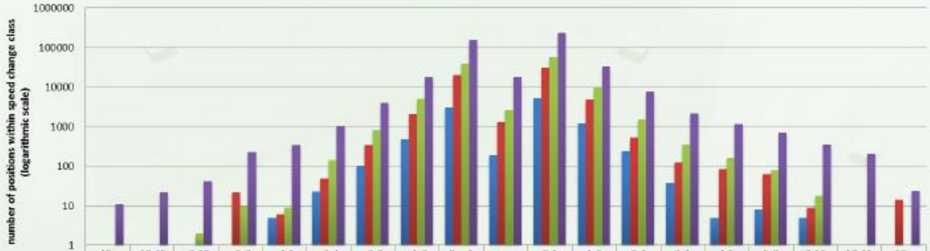
Frequency distribution of turnangle classes after intersections



	-165°-180°	-150°-165°	-135°-150°	-120°-135°	-105°-120°	-90°-105°	-75°-90°	-60°-75°	-45°-60°	-30°-45°	-15°-30°	0°-15°	0°
turnangle_2006	312	173	160	196	209	216	348	407	632	602	801	1046	72
turnangle_2007	1878	1397	1311	1083	1641	1748	1933	2268	3347	3598	4180	4874	139
turnangle_2008	3339	2460	2335	2238	2549	3201	3530	4793	5864	7952	9635	11036	85
turnangle_2009	24346	18434	14700	12239	12741	13475	14955	17089	19021	25579	32757	36104	392

	0°-15°	15°-30°	30°-45°	45°-60°	60°-75°	75°-90°	90°-105°	105°-120°	120°-135°	135°-150°	150°-165°	165°-180°
turnangle_2006	968	803	755	569	432	375	282	195	215	369	207	278
turnangle_2007	5003	4975	4115	3377	2549	2304	1737	1713	1590	1210	1522	1752
turnangle_2008	11282	10387	7452	5792	4544	3459	2950	2750	2499	2138	2874	3801
turnangle_2009	37378	32096	25817	20699	15727	13844	13100	11989	12387	14537	16806	25095

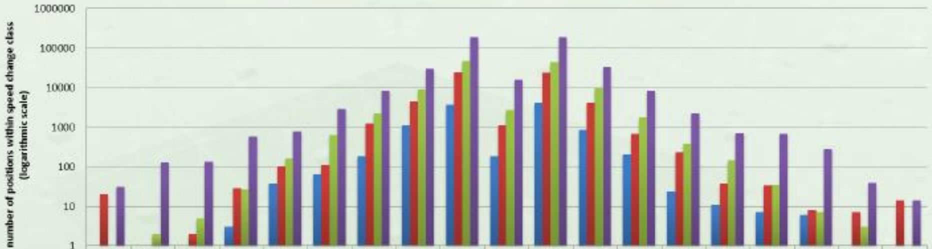
Frequency distribution of speed change classes (speed diff1)



	-15+ km/h	-10-15 km/h	- 7-10 km/h	- 5-7 km/h	- 4-5 km/h	- 3-4 km/h	- 2-3 km/h	- 1-2 km/h	0 - -1 km/h	0 km/h
speed_change1_2006	0	0	0	0	5	23	105	481	3124	192
speed_change1_2007	0	0	0	22	6	49	346	2073	20497	1300
speed_change1_2008	0	0	2	10	9	142	843	5057	39726	2606
speed_change1_2009	11	22	42	223	347	1033	4025	17679	154962	18152

	0-1 km/h	1-2 km/h	2-3 km/h	3-4 km/h	4-5 km/h	5-7 km/h	7-10 km/h	10-15 km/h	15+ km/h
speed_change1_2006	5202	1194	239	38	5	8	5	0	1
speed_change1_2007	31300	4816	537	126	85	64	9	0	14
speed_change1_2008	58778	9589	1558	362	165	80	18	0	0
speed_change1_2009	238987	33596	7583	2186	1171	710	352	202	24

Frequency distribution of speed change classes (speed diff2)



	-15+ km/h	-10-15 km/h	- 7-10 km/h	- 5-7 km/h	- 4-5 km/h	- 3-4 km/h	- 2-3 km/h	- 1-2 km/h	0 - -1 km/h	0 km/h
speed_change2_2006	0	0	0	3	37	66	187	1123	3799	188
speed_change2_2007	20	0	2	29	102	112	1241	4550	24979	1105
speed_change2_2008	0	2	5	27	162	645	2196	9086	47074	2663
speed_change2_2009	31	131	136	582	786	2901	8583	30108	190333	15543

	0-1 km/h	1-2 km/h	2-3 km/h	3-4 km/h	4-5 km/h	5-7 km/h	7-10 km/h	10-15 km/h	15+ km/h
speed_change2_2006	4095	869	207	24	11	7	6	0	0
speed_change2_2007	23986	4103	677	237	38	34	8	7	14
speed_change2_2008	45115	9631	1761	383	150	35	7	3	0
speed_change2_2009	186510	33254	8450	2239	707	676	284	39	14

RESULTS RQ 2 - ENCOUNTERS 100m

On the following two pages, results regarding the duration of encounters are presented. On this page, encounters with a spatial threshold of 100m around the positions are shown, the next page contains the results for 200m threshold. These spatial thresholds have been chosen mainly due to GPS inaccuracy, which can double when regarding the positions of two individuals. The temporal threshold is the same for results on both pages (+/- 15 minutes).

The value '0' represents encounters where two individuals 'met' each other, but did not stay together and continued their movement. Such short encounters can also be included in the other values. Information on the amount of encounters according to sex or reproductive status combination is available as well.

Abbreviations:

SAM - sub adult male

AM - adult male

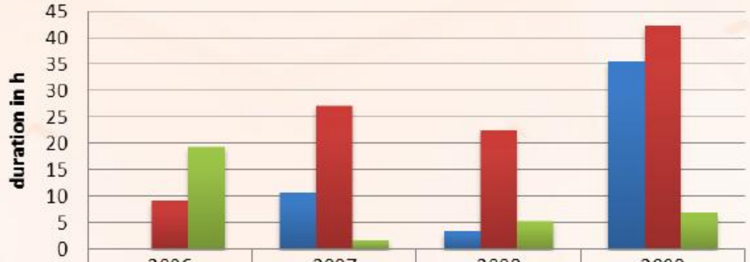
SAF - sub adult female

RF - reproductive female

COY - female with cub(s) of the year

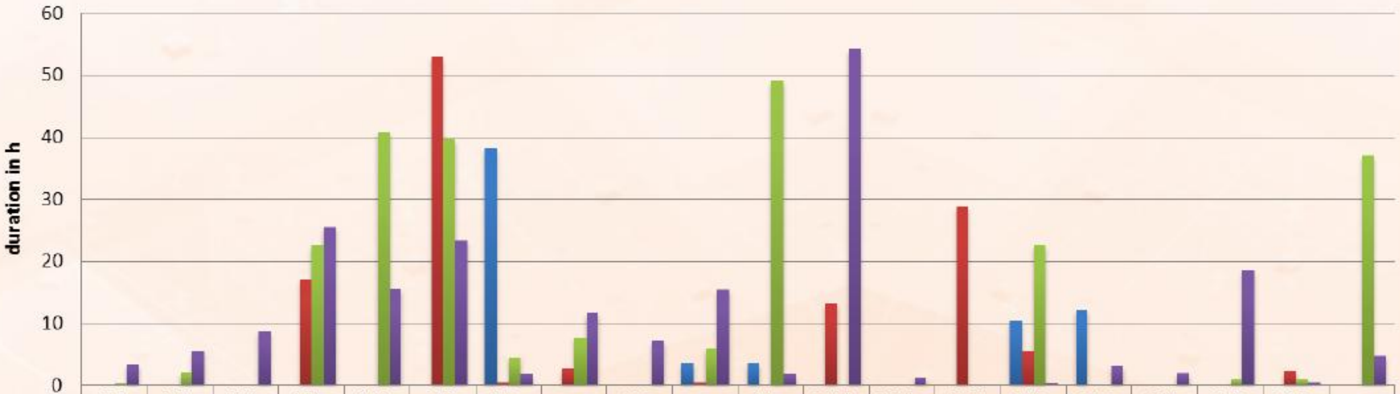
YL - female with yearling(s)

Mean encounter duration according to sex (100m)



	2006	2007	2008	2009
M-M		10.8	3.39	35.58
M-F	9.16	27.12	22.59	42.45
F-F	19.41	1.68	5.4	6.88

Mean encounter duration (h) according to RS (100m)



	AM - SAM	AM - AM	AM - SAF	AM - RF	AM - COY	AM - YL	RF - SAF	RF - RF	RF - COY	RF - YL	RF - SAM	SAM - SAM	SAM - COY	SAM - YL	SAF - SAM	SAF - SAF	SAF - COY	COY - YL	SAF - YL	no data
2006							38.17			3.56	3.53				10.29	12.05				
2007	0		0	17.05		52.91	0.49	2.71	0	0.37	0	13.11		28.82	5.48		0.17		2.31	0
2008	0.18	2.13	0	22.51	40.84	39.57	4.44	7.68		5.81	49.01			0	22.5			1	1	37
2009	3.46	5.51	8.66	25.54	15.51	23.33	1.81	11.63	7.24	15.4	1.73	54.2	1.21		0.26	3.14	1.84	18.5	0.49	4.74

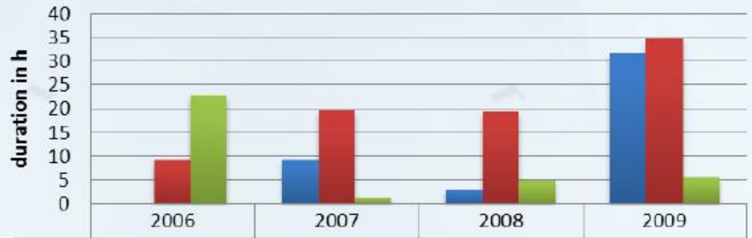
one outlier has been removed in this graph: SAM—YL —> 420.4h (2009)

RESULTS RQ 2 - ENCOUNTERS 200m

This page shows results of research question 2 with the spatial threshold of 200m. Striking is, that although higher peak durations of encounters can be seen, in overall the durations go down. The numbers of the encounters however, go up (628 encounters for 100m threshold, 793 encounters for 200m threshold). Some of the encounters which had a duration of '0' turn out to not be only short meetings where individuals do not stay together like supposed with a 100m threshold. Admittedly, this does not necessarily mean that the two individuals are really together very close (as the positions can be as far apart as 200m).

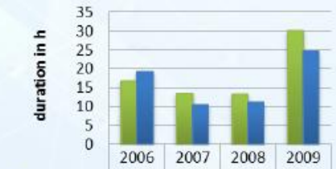
The two smaller graphs below show a comparison in mean and maximum durations of encounters with the two spatial thresholds. The longest encounter in 2009 covers the whole mating season and belongs to a mother with two cubs (W0104, W0901, W0902).

Mean encounter duration according to sex (200m)



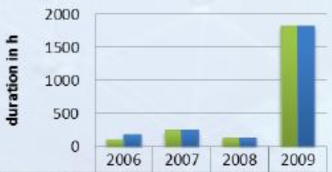
	2006	2007	2008	2009
M-M		9.21	3.02	31.8
M-F	9.16	19.64	19.34	34.64
F-F	22.76	1.41	4.87	5.65

Mean duration in hours



	2006	2007	2008	2009
mean 100m	16.85	13.56	13.37	30.12
mean 200m	19.21	10.48	11.14	24.6

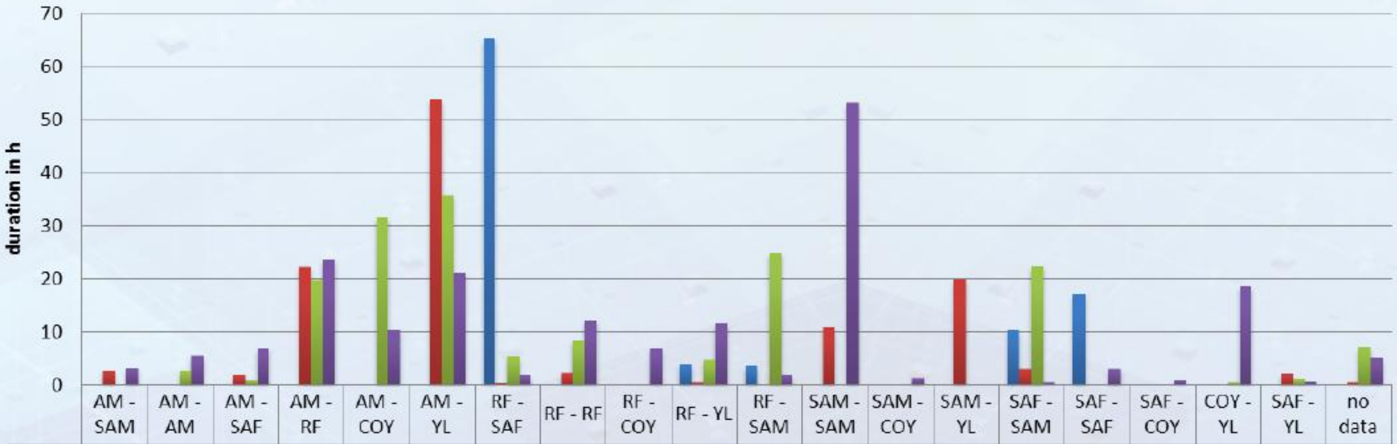
Max duration in hours



	2006	2007	2008	2009
max 100m	97.48	244.49	124.02	1823.83
max 200m	172.48	244.99	124.02	1823.83

one outlier has been removed in this graph: SAM—YL —> 298h (2009)

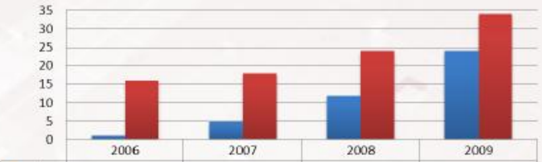
Mean encounter duration (h) according to RS (200m)



	AM - SAM	AM - AM	AM - SAF	AM - RF	AM - COY	AM - YL	RF - SAF	RF - RF	RF - COY	RF - YL	RF - SAM	SAM - SAM	SAM - COY	SAM - YL	SAF - SAM	SAF - SAF	SAF - COY	COY - YL	SAF - YL	no data
2006							65.18			4	3.53				10.29	16.99				
2007	2.7		1.83	22.31		53.74	0.33	2.29	0	0.5	0.07	10.92		19.84	2.99		0.13		2.08	0.5
2008	0.17	2.57	0.83	19.76	31.61	35.7	5.25	8.45	0	4.71	25			0	22.5			0.5	0.99	7.02
2009	3.18	5.52	6.87	23.56	10.35	21.02	1.77	11.99	6.82	11.62	1.82	53.24	1.21		0.47	3.04	0.95	18.5	0.65	5.15

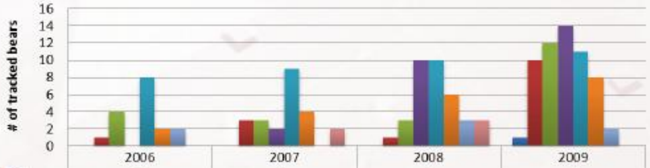
RQ 2—MORE INFORMATION

male - female distribution of tracked bears



	2006	2007	2008	2009
males	1	5	12	24
females	16	18	24	34

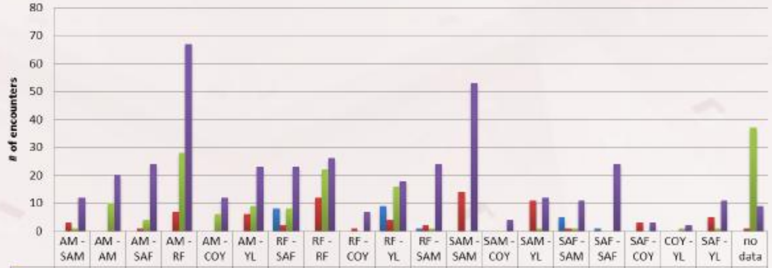
RS distribution of tracked bears



	2006	2007	2008	2009
D	0	0	0	1
SAM	1	3	1	10
SAF	4	3	3	12
AM	0	2	10	14
RF	8	9	10	11
COY	2	4	6	8
YL	2	0	3	2
no data	0	2	3	0

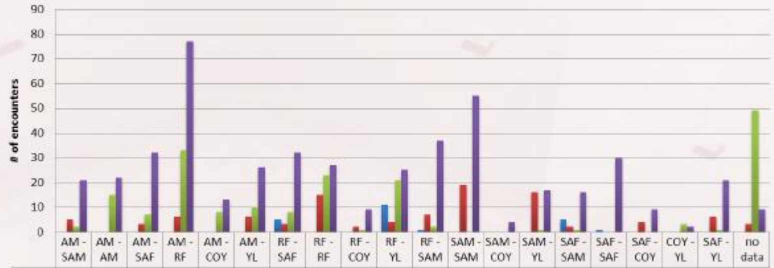
note that RS can change during the year

numbers of encounters according to RS (100m)



	AM - SAM	AM - AM	AM - SAF	AM - RF	AM - COY	AM - YL	RF - SAF	RF - RF	RF - COY	RF - YL	RF - SAM	SAM - SAM	SAM - COY	SAM - YL	SAF - SAM	SAF - SAF	SAF - COY	COY - YL	SAF - YL	no data
2006							8			9	1				5	1				
2007	3		1	7		6	2	12	1	4	2	14		11	1		3		5	1
2008	1	10	4	28	6	9	8	22		16	1			1	1			1	1	37
2009	12	20	24	67	12	23	23	26	7	18	24	53	4	12	11	24	3	2	11	9

numbers of encounters according to RS (200m)



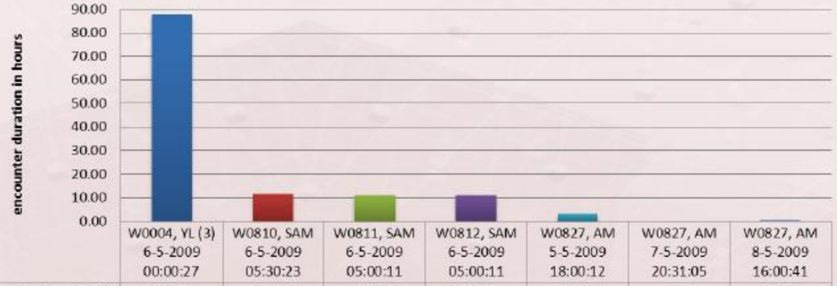
	AM - SAM	AM - AM	AM - SAF	AM - RF	AM - COY	AM - YL	RF - SAF	RF - RF	RF - COY	RF - YL	RF - SAM	SAM - SAM	SAM - COY	SAM - YL	SAF - SAM	SAF - SAF	SAF - COY	COY - YL	SAF - YL	no data
2006							5			11	1				5	1				
2007	5		3	6		6	3	15	2	4	7	19		16	2		4		6	3
2008	2	15	7	33	8	10	8	23	1	21	2			1	1			3	1	49
2009	21	22	32	77	13	26	32	27	9	25	37	55	4	17	16	30	9	2	21	9

RQ 2—AN EXAMPLE

It is known from the base data that the reproductive status of bear 'W0004' changed from 'YL' to 'RF' around May 5th/6th 2009. The graph on the right shows the encounters of bear 'W0805', an adult male, around this date. It can be seen, that he first encounters the mother, later on also her cubs ('W0810', 'W0811', 'W0812'). His encounter with the cubs lasts around 11 hours, whereas he stays with the mother for almost 90 hours. After these encounters, the cubs did not return to the mother.

In a next step, the encounters of the cubs could be analysed/presented in the same way, showing their behaviour after this obvious family breakup.

Vattun (AM) - encounters 5-5-2009 - 9-5-2009 (200m)



	W0004, YL (3) 6-5-2009 00:00:27	W0810, SAM 6-5-2009 05:30:23	W0811, SAM 6-5-2009 05:00:11	W0812, SAM 6-5-2009 05:00:11	W0827, AM 5-5-2009 18:00:12	W0827, AM 7-5-2009 20:31:05	W0827, AM 8-5-2009 16:00:41
encounter duration (h)	87.51	11.50	11.00	11.00	3.00	0.00	0.49

Please note, that the presented results are averages of all individuals per year. More detailed results and graphs are available, but have not been included in this information leaflet.

GENERAL QUESTIONS

1) Are the results as presented understandable?

2) Are the generated results in general of interest/use for studying brown bear behaviour?

3) Do they deliver any new knowledge to you?

4) Can you think of any further (statistical) tests/analyses in order to find patterns in behaviour out of the results?

5) Do you think, that the results (of both research questions) can be used as a basis for an additional visual analysis of the spatial datasets?

6) Can this analysis in your opinion also be applied/be of interest on/for other species, or even on interspecies applications?

QUESTIONS RQ 1

7) The change in speed has been calculated in two versions. Is one of them preferable or are both of them of interest? Or should more steps before and after an intersection be taken into account (and eventually be averaged) for calculating a change in speed (implying that this also has to be adapted for the calculation of change in direction)?

8) The age of the crossed track has been grouped into five classes (<24h, 24h-72h, 72h-168h, 168h-336h and >336h). Are these selected temporal time spans useful/sufficient or would you prefer additional/different options (i.e. 6h, 12h, etc.)?

9) The presented graphs show results grouped together by sex for example. However, they are based on results of individual bears, meaning that you can access results for every single bear that was tracked and intersected the track of another tracked bear. Does that offer more possibilities of further analysis/interpretation for you, or are the grouped results more interesting?

10) Would the information about change in direction be more valuable for you, if the bearing *after the crossing* of a track in relation to the bearing of the *crossed track* would also be known (meaning a bear could change to the same direction as the crossed track or to a completely different one; this also could be the basis for tracking analysis)?

QUESTIONS RQ 2

11) Several spatial and temporal parameters were set during the analysis:

- *100m/200m spatial threshold/buffer around positions defining two individuals being 'together' at the same spatial location*

12) According to my experience during fieldwork, the accuracy of the GPS collars is quite good. However, not all positions will have this high accuracy. Are these thresholds in your opinion well chosen or could you even imagine to use for example a 50m buffer?

- *+/- 15 minutes temporal threshold around positions defining two individuals being 'together' at the same time*

13) Is this a good value to consider two positions the same in time (considering mean logging frequencies; Figure 1) or should this threshold be flexible according to current logging frequency (of the individuals involved in the actual encounter) or mean logging frequencies per year for example?

- *maximum 5h between positions within coherent encounters*

14) This threshold makes sure that encounters will not be split up due to missing records of positions (i.e. 10 minutes logging frequency, but record 'n' was recorded at '14:00;17' and the next position 'n+1' was recorded at '15:10:04' due to GPS issues). On the other hand it can also just be that the individuals in fact are not close together for a certain period, but come together again. Would you consider the set threshold of 5 hours to be suitable or would you prefer a higher/lower value here?

15) Can the obtained results (also per individual) be used for further ecological analysis, may they even give new insights in brown bear behaviour?

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16) Would you like to use the analysis also for current and future movement data?

17) Are the methods, how the results were obtained, valid in your opinion?

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