GPS Collars in Studies of Cattle Movement: Cases of Northeast Namibia and North Finland

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Chapter 12
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12.1 Introduction

The deployment of the US Global Positioning System can be seen as a mega-engineering project in itself. This GPS system consists of 24 satellites and has been operational since 1978; in 1984 the system has been open for civilian use. Spin off from this new technology has been a whole industry based upon GPS-navigation. This together with the advances in Geographical Information Systems (GIS) software has created industries based upon location based knowledge. We can give exact locations to any object, person or process on the surface of the earth, enabling us to produce real time spatial databases. How to incorporate traditional and indigenous knowledge into GIS-data is a fascinating problem. People's memory of time and place is not exact, but there are markers in space and time which can be used to relate indigenous knowledge with more exact forms of data. Allowing for traditional forms of land use in a world dominated by other more advanced and intensive forms of land use is probably a very demanding task. There will be a need to integrate traditional knowledge with exact data on land use, wildlife, conservation, environment and management. This is definitely an important issue in engineering earth and the environment.

Animal behavior and habitat use have been studied by direct observation and radio telemetry. Both methods are labor intensive and time consuming. These studies are very sensitive to factors like number of animals tracked and the length of tracking time, both of which are often reduced by the amount of available resources (Resources Information Standards Committee, 1998). Satellite tracking systems like Argos are available for the long range tracking of migratory animals, however, the cost is considerable. The development of the Global Positioning System (GPS) with global coverage and accuracy of up to 15 m (49.2 ft) has provided a cost effective way to monitor animals on a regional scale. At present researchers have a range of telemetry options available for animals ranging from fish and marine mammal to

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reptiles, birds and terrestrial mammals. These options include a variety of methods for data collection and storage/transmission, ranging from VHF radio-telemetry to Argos satellite tracking and GPS collars with built in GSM-data transmission.

This chapter presents two case studies using GPS collar tracking domestic (bovine cattle in Namibia) and semidomestic (reindeer in Northern-Finland). The case studies show the merits and drawbacks of GPS collar tracking in two very different regions and testing the equipment under very different climate regimes (cold/hot, wet/dry).

12.2 GPS Collars in Animal Tracking

Global Positioning System (GPS) telemetry is a widely used method in studies of animal movement, habitat use and resource selection. The method has also been used in monitoring semi-domestic reindeer (Kumpula & Colpaert 2007; Kumpula, Colpaert, & Anttonen, 2007) and domestic cattle grazing (e.g. Agouridis et al., 2004; Bailey, Keil, & Rittenhouse, 2004; Turner, Udal, Larson, & Shearer, 2000). GPS collars have many benefits in studies of animal movement: the collars enable tracking of an individual animal over a long period of time and automatically record geographical position at predefined time intervals. However, GPS collars are expensive and malfunction or total failure of some devices is unavoidable. Aim of the GPS tracking is to produce reliable and accurate data about the movements of an animal. However, various environmental factors influence the availability, quality and strength of satellite signals received by a GPS collar, all potentially leading often to unsuccessful fix attempts and increased positional errors. Terrain obstructions (Cain, Krausman, Jansen, & Morgart, 2005; D'Eon, Serrouya, Smith, & Kochanny, 2002; Lewis, Rachlow, Garton, & Vierling, 2007) and vegetation characteristics such as canopy cover and tree height (Agouridis et al., 2004; DeCesare, Squires, & Kolbe, 2005; Di Orio, Callas, & Schaefer, 2003; Frair et al., 2004; Hansen & Riggs, 2008; Lewis et al., 2007) are additional examples of environmental factors that may interfere with the connections between satellites and GPS receivers. Systematic failure in fix attempts and the inaccuracy of positions also have an influence on the analyses of animal locations and movements (e.g. Frair et al., 2004; Jerde & Visscher, 2005).

12.2.1 Case Study A: GPS Tracking of Domestic Bovine Cattle in East Caprivi, Northeast Namibia

During 2006 and 2007, we collected GPS data to study bovine cattle grazing and movement patterns in East Caprivi, Northeast Namibia. The study area is the Salambala conservancy and the floodplains of the Zambezi River and its tributary, the Chobe River (Fig. 12.1). The area is characterized by a flat floodplain, about 900 m above sea level (2950 ft). The climate has a dry and a rainy season, at the end of which the area is affected by sometimes severe flooding of the Zambezi River. The

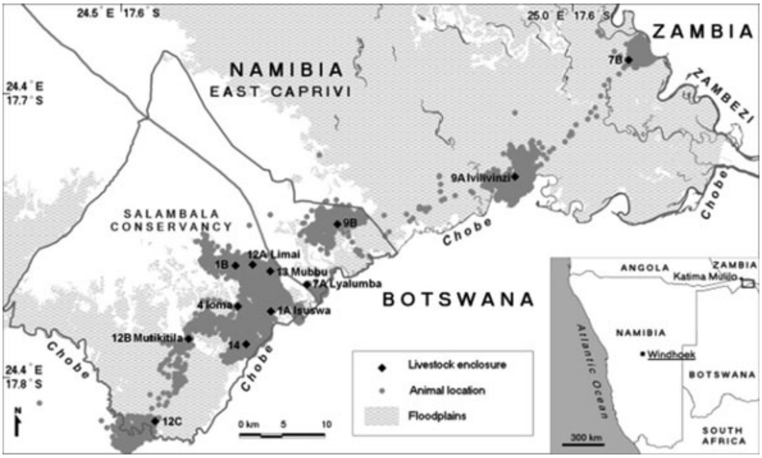

Fig. 12.1 Location of study area, cattle enclosures and tracking data

Fig. 12.2 Typical livestock enclosure, often called a "kraal." (Photo: Katja Polojärvi)

population of East Caprivi is dependent upon small scale farming and cattle breeding in a fragile environment. Cattle are owned by extended families, which may live in a village near the grazing area or elsewhere. The cattle are kept overnight in enclosures and are herded during daytime on grazing grounds around the village (Figs. 12.2 and 12.3).

The cattle a family owns can be seen as a "savings account," from which animals are taken to market to provide cash when needed. Local land use for farming, cattle

Fig. 12.3 Cattle grazing on the Zambezi/Chobe floodplain. (Photo: Katja Polojärvi)

breeding, tourism and conservancy is also becoming more intensive, a development which creates tensions in the traditional tribal land management and has negative effects on the size and quality of pasturelands. An aim of the cattle tracking study is to produce information about the extent of the grazing areas, including the daily movement, and the grazing pattern of the cattle. GPS collar data combined with pasture maps based on satellite image classification and GIS, also enable one to identify both overgrazed and underused grazing areas. The information about the grazing patterns will be combined with results of a study of indigenous knowledge and social structures in land use decision making.

During 2006 and 2007 a total 14 Televilt Tellus Basic 5H2D v2.0 (store onboard) GPS collars (Televilt/Followit Lindesberg Ab, Sweden) were attached to bovine cattle (Caprivi Sanga) in ten villages of East Caprivi (Fig. 12.4).

The GPS collars tracked the cattle and recorded their location at 1 h intervals. The collars were retrieved after a 1 year tracking period. The downloaded data files have hourly recorded information about the location of the animal. In addition to the date, time, and geographic coordinates, the collars also record the following information (Televilt, 2006):

- Time (s) the GPS receiver has used to obtain the fix.
- Number of the satellites used to obtain the fix.
- Altitude (m) when at least four satellites are available.
- 2D3D: the obtained fixes are three-dimensional when the collar has contact with four or more satellites. Otherwise the obtained fixes are two-dimensional.

Fig. 12.4 Bull fitted with GPS collar. (Photo: Katja Polojärvi)

- DOP: dilution of precision is a measure of the quality of the GPS data being received from the satellites.
- FOM: figure of merit values indicates the best accuracy achievable from the satellites being tracked.
- Temperature (C°) inside the main housing at the time the position was obtained.
- X,Y: The activity level that is measured as a certain change in collar position during the time the collar has been used to obtain the fix.

Tracking period and amount of data varied due to several technical reasons. Seven collars were lost, destroyed completely or had serious malfunctions. Seven collars with the longest operation periods had recorded location data from 3 months to almost 1 year (Table 12.1). Locations obtained in the night-time, when the cattle are gathered inside the livestock enclosures, revealed that a significant proportion of the locations were inaccurate. The fix rate of the collars was very good, varying from 93 to 99.6%, meaning that the GPS receivers worked very well when they were undamaged and correctly in place. Accuracy assessment derived from the enclosure data showed that about 8.5% of the fixes were inaccurate, 50% of these positions had a positional error below 21 m (69 ft), and 95% of all error was within 175 m (574 ft). We used data of seven GPS collars for accuracy assessment and testing of different data screening options as a way to reduce location error. Basic analysis showed that simple measures of accuracy like DOP and FOM alone are not sufficient to remove erroneous locations. We removed the locations with the following condition: 2D fix and DOP> 6 or 0 <altitude< 850 m (2789 ft) or altitude> 1050 m (3345 ft) or DOP≥ 10 or FOM≥ 10 or walking speed of the animal was over 4.5 km (2.8 mi/h). This

Table 12.1 Number of successfully obtained fixes, fix rates (%) and operation periods of the GPS collars

				Operation period		
Collar	Village	Fixes	Fix rate %	Enclosure	From	To
1	Isuswa	5528	96.8	1A	1.7.2006	20.8.2006
					29.11.2006	7.3.2007
				1B	7.3.2007	4.6.2007
4	Ioma	2098	96.8	4	2.7.2006	30.9.2006
7	Lyalumba	4868	95.9	7A	4.7.2006	23.8.2006
				7B	23.8.2006	1.2.2007
9	Ivilivinzi	7778	97.0	9A	6.7.2006	18.2.2007
				9B	18.2.2007	5.6.2007
12	Limai/Mutikitila	7053	90.3	12A	7.1.2007	1.6.2007
				12B	7.6.2007	15.8.2007
				12C	15.8.2007	4.12.2007
13	Mubbu	3848	86.4	13	5.6.2007	7.12.2007
14	Limai	4344	97.1	14	4.6.2007	7.12.2007

data screening option was able to eliminate 75% of the most erroneous locations that were located more than 300 m (984 ft) from the livestock enclosures; it retained 97.2% of the locations that were correctly located inside the livestock enclosures. Before data screening, 95% of the night-time locations that were located outside the livestock enclosures were located 70–406 m (230–1332 ft) from the enclosures. The maximum error was over 10 km (6.2 mi). After data screening, 95% of the locations were 74–298 m (243–978 ft) from the enclosures; the maximum error was 4423 m (14,511 ft) (Polojärvi, Colpaert, & Matengu, 2009).

The data showed that the daily movement was related to the advancement of the dry season. The herd starts from the cattle enclosure where they are kept for the night (around sunrise 5–7 AM GMT) and moves to the nearest pasture grounds, from there, returns to the enclosure before dark (4–6 PM GMT). The length of the average daily trips varies from 2 to 3 km (1.2–1.9 mi). Speed during grazing is about 1 km/h (0.6 mi/h), maximum speed was about 4.5 km/h (1.7 mph) (Fig. 12.5). When the grazing land becomes poorer, the length of the daily trips increases, until the herd is moved to a new enclosure in fresh grazing areas. It must be noted that the cattle are not grazing freely, but are guarded by herd boys (usually young boys from neighboring Zambia). The herd boys take the herd to the grazing grounds according to grazing conditions and seem to work without much interference by the owners of the cattle.

Many farmers reported that they did not know how much distance their cattle travelled on a daily basis. Notwithstanding the fact that the cultural land

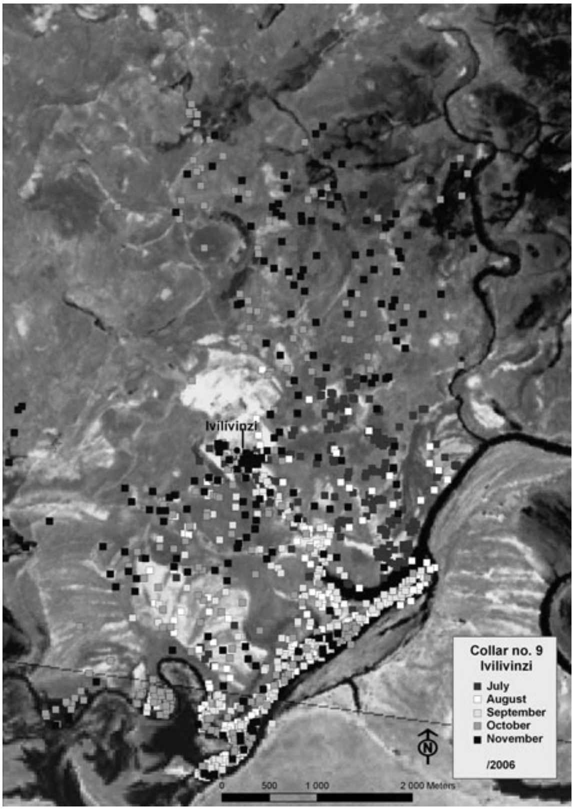

Fig. 12.5 Tracking data from collar no. 9 during July–November 2006

administration system in the area of study is somewhat fuzzy (in the sense that traditional authorities in principle have the powers to dictate how the land and the benefits from the land are to be apportioned, they do not have the means to enforce prudent land management), data on the movement of cattle could facilitate the implementation of various instruments to enable animal husbandry to be economical. For instance, on one hand, when cattle movement data coming from GPS collars are analyzed in combination with key informant interviews of the farmers, it becomes clear that the current pasture "management" and livestock farming systems reflect in principle the social relationship between people concerning sharing of grazing land and the perceived administration protocols. The data can be utilized to devise a contextual system of management where greater emphasis would be placed on reducing distance traveled on a daily basis, which consequently can lead to increased mass (kg) and livestock productivity. On the other hand, these datasets can also be used to predict the interaction of cattle with wild animals such as buffalos and elephants, which may carry foot and mouth disease (FMD) and anthrax, respectively. GPS data, therefore, can be an essential tool for monitoring and mapping the movement of cattle and areas with frequent animal disease outbreaks.

One of the main benefits of this research is that it provides data that agricultural extension officers and veterinarians can use to provide advice to cattle farmers. Unlike many other GIS applications which provide information about the geographical attributes of an area, the data recorded in this research also reflect the social relationships farmers have among themselves and between them and their land. The challenge to the study included the fact that the way grazing land rights are understood by the individuals is dependent on their own understanding of land administration, knowledge which is not written. In addition, the movement of cattle is not necessarily related to the palatability of the grass or the availability of grass. Instead, it may, as in some cases, be related to the choice of a herd boy. This finding poses a challenge because we are not interested in the movement of cattle per se, rather in the reason why the movement pattern is what it is. It would be possible to understand the cattle movement pattern better if the study is undertaken over a period of time, at least 5 years.

It is worth remembering that data recorded in a communal land administration system have a social and cultural meaning and these meanings are based on accepted social norms and practices. The movement of cattle from the flood-prone areas to the hinterland is not entirely a choice of the owner. Instead, the choice is in fact linked to the social relationship of the owner and the area to which the livestock will be placed for periods of up to 6 months. It is not whether there are laid down rules, rather, it is a question of following the unwritten customs, in which concepts of social existence and dependence are grounded. Therefore GPS data should not be seen to be a mere indication of how and where the cattle move; it is also an impression of the rules of investments in the system, that is, the way the social system operates and the way the owners try to maintain control of grazing. In addition, cattle farming is not a purpose in itself; it is part of the broader socioeconomic system of land administration and property development that is normally seen as a way of strengthening the role of the communal farmers' sustenance. Without this perspective cattle farming is lacking societal and legal meaning. Residents the study area emphasize that grazing can take place anywhere provided that it does not result in operational constraints on others. It would be interesting to try to use data on cattle movement and to relate it to grazing land administration and poverty reduction as well as to attitudes and sustainable agriculture. Also how can the GPS data be used to improve the land tenure security? And what influence does distance travelled play in the justification of land ownership?

12.2.2 Case Study B: Analyzing Pasture Use of Semidomestic Reindeer in Finnish Lapland with GPS Collar Tracking

Well adapted to the Arctic climate, reindeer and caribou thrive in the harsh conditions of the circumpolar area. Reindeer and caribou utilize grasses, leaves and other green plants during the short Arctic summer and survive the harsh winter by digging for ground lichens. In forested areas also arboreal lichens can be part of their winter diet.

In Finnish Lapland semidomesticated reindeer are owned by both Sami and Finnish herders. Reindeer herding is in the core of Sami tradition and has an important social and economic role in many peripheral areas in the north. Coniferous forests cover over two thirds of the reindeer herding area in Finland, and most of these areas are designated as commercial forests. Forest harvesting has gradually changed the composition and age structure of commercial forests especially during the past 50 years (Mattila, 1996; Tomppo & Henttonen, 1996). At the same time, the reindeer herding system in Finland had been intensifying the exploitation of the pastureland. Calf slaughtering, supplementary winter-feeding and anti-parasitic treatment of reindeer have made reindeer herds increasingly less vulnerable to natural population regulation mechanisms and enabled herders to maintain average reindeer densities at a level where winter pastures have gradually become overgrazed in many areas (Kojola & Helle, 1993; Kojola, Aikio, & Helle, 1993; Kojola, Helle, Niskanen, & Aikio, 1995; Kumpula, 2001; Kumpula, Colpaert, & Nieminen, 2000; Väre, Ohtonen, & Mikkola, 1996). The complicated process of deterioration and reduction of winter ranges made reindeer herding more dependent on supplementary winter-feeding, creating extra costs for the herders and reducing profit margins (Kumpula, 2001).

Besides global climatic fluctuations (e.g. North Atlantic Oscillation and Arctic Oscillation), there are several geographical and local factors, such as altitude, exposition or vegetation patterns, which can affect snow conditions within a certain area (Hiemstra, Liston, & Reiners, 2002; Tappeiner, Tappeiner, Aschenwald, Tasser, & Ostendorf, 2001; Vajda, Venäläinen, Hänninen, & Sutinen, 2006). Large scale human operations, such as forest harvesting, may also affect snow conditions, especially in large felling areas where the forest canopy is considerably reduced (D'Eon, 2004; Eriksson, 1976; Kirchoff & Schoen, 1987; Koivusalo & Kokkonen, 2002).

There is disagreement between the forest industry and reindeer herding, viz., how forestry operations, in fact, change the usability value and snow conditions of reindeer pastureland. Reindeer herders acknowledge that forest openings do not only destroy arboreal lichen pastures (old growth forests), but also reduce amount of terrestrial lichens and disturb the winter grazing of reindeer. Since felling residue covers the soil surface and snow conditions can become more difficult in felling areas than in untouched old growth forests. Besides these factors, forest openings and forest roads may split a continuous winter pasture areas which makes reindeer herding more difficult. On the other hand, forest thinning may improve growth conditions of terrestrial lichens since light increases on the bottom layer of vegetation. Also the amounts of hays and grasses may considerably increase in submesic forest openings after cutting, which then offers plenty of green fodder for reindeer.

In order to clarify the effects of forest management and snow conditions on the winter grazing value of pastureland we studied pasture use by reindeer in two reindeer herding districts located in the northern boreal forest area of Finland. The studied questions were:

1. Do reindeer prefer or avoid different kinds of forest habitats during different seasons?

2. Are old growth forests still as important for reindeer and reindeer herding during winter as many herders emphasize?
3. Do human perturbations such the constructions of roads and power lines on pastureland cause disturbance for reindeer?
4. How do snow conditions vary within a rugged pine forest landscape utilized by forest industry?
5. What are the relative effects of local factors (effects of elevation, slope aspect, and forest age structure) on snow conditions compared to interannual weather variation?
6. Do snow conditions affect pasture selection by reindeer during winter in a pine forest landscape?

From December 1999 to November 2002, we tracked 29 female reindeer in the Ivalo herding district using GPS collars produced by VECTRONIC Aerospace GmbH in Germany (model types GPS 2000 and GPS PLUS) (Fig. 12.6). The collar weight varied between 0.55 and 0.7 kg (1.2–1.5 pounds) depending on the model. The collars were programmed to measure the location of a reindeer with an interval of 8 h. We assumed that this interval was suitable for data collection on the basis of mobility of reindeer as well as the battery capacity of GPS collars. The data were stored in the GPS memory and downloaded after retrieval of the collars. Due to problems in GPS engineering, primarily reduced battery life, the total amount of locations obtained with a GPS collar varied from 32 to 1075 locations. The oldest types of our collars were programmed to indicate the accuracy of each location only as validated or invalidated, meaning that at least five satellites were available and the DOP value was below ten. For the study, we used only observations with a validated

Fig. 12.6 During 2002–2005 altogether 40 female reindeer were tracked by GPS collars in the Oraniemi reindeer herding district, Middle-Lapland. (Photo: Dr. Jouko Kumpula)

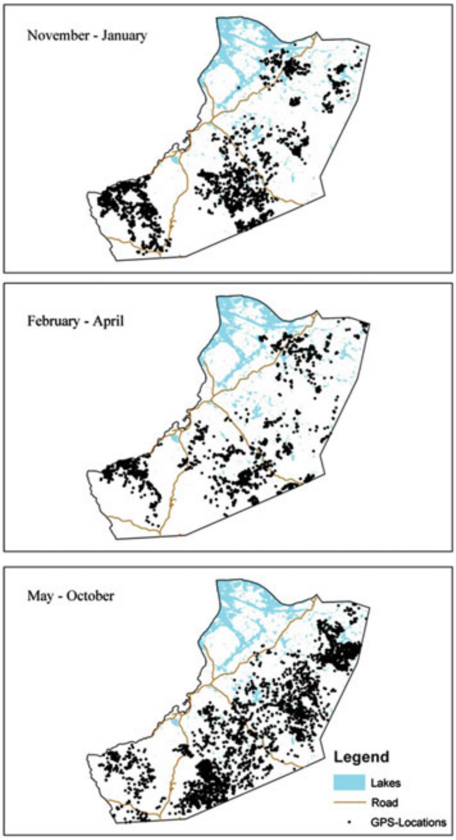

Fig. 12.7 All locations of GPS-tracked female reindeer ($n = 29$) from 1999 to 2002 (10,981 locations) in the Ivalo reindeer herding district and classified into three seasonal periods

status. During the entire study period we received a total of 10,977 valid locations (Fig. 12.7).

During the years 2002–2005 we tracked 40 female reindeer in the Oraniemi district using both GPS PLUS and GSM GPS-PLUS collars. The GSM-GPS models send the data to a base station over the mobile telephone network using SMS messages. When the animals roamed in areas outside the network, locations were stored on board and sent when the collar was able to contact the network again. We used the same 8 h interval between fixes as before in order to extend battery life. The fix rate of the newer collars was higher and we obtained over 30,000 locations. Inaccurate locations and also locations (DOP > 10 and < 5 satellites) situated inside corrals and feeding places or their vicinity were removed. After that 22,845 locations remained and these were divided into four groups according to the main seasons. It seems that during our study the accuracy and working reliability of the collars increased as the model types developed. The theoretical battery life of these collars is over 1 year, but due to the harsh winter conditions, collars had problems and in the worst cases functioned only two weeks; the best worked well over 1 year.

The tracking data were integrated in our GIS system together with other relevant data like DEM, roads and other topographical data, forest stand data, and a satellite image derived pasture map. The pasture map was produced by a semisupervised maximum likelihood classifier from Landsat TM, ETM and Aster images. The pasture selection by reindeer was analysed using the two level Compositional Analysis (CA) where preference of habitats in different seasonal periods was first analysed in the selection of home range area followed by use within this home range, respectively. In this analysis we compared random vs. non-random pasture use and testing avoidance/attraction of different pasture types.

In the Ivalo district, which is located in the pine forest area, the reindeer preferred old growth forest (both lichen and hay dominated) and avoided felling areas and linear infrastructure (forest roads and power lines) in the selection and use of their wintering areas. Old growth pine forest had a high preference value especially in late winter. However, during early winter season, when snow conditions were still relatively easy, the study reindeer in the Ivalo district also used sapling stands and young cultivation forests (Kumpula et al., 2007).

In the Oraniemi district which is located in the spruce forest area and where old growth forests are more fragmented than in the Ivalo district, the reindeer did not show a clear preference to old growth forests when selecting winter home range area. However, when using late winter home range areas reindeer clearly preferred old spruce forests and avoided young and dense mixed forests. Use of both lichen and hay dominated felling and sapling stand areas were also relatively high in winter home range areas. In late winter reindeer were also attracted to new logging sites to forage arboreal lichens from crown and branches of felled trees (Kumpula, Colpaert, & Tanskanen, 2008).

Interannual weather variation mostly affected the depth, density and hardness of snow in the Ivalo herding district. At the forest landscape level, snow depth and density increased with altitude. The thinnest and deepest snow cover occurred on western and northern slopes, respectively. In contrast, forest harvesting did not seem to affect snow conditions. From spring to autumn, reindeer mainly used higher altitude pastures. In early and mid-winter, when snow conditions were easy or moderate, reindeer still preferred higher altitudes, but in late winter when snow conditions and food accession were at their most difficult, they preferred lower altitudes (Fig. 12.8) (Kumpula & Colpaert, 2007).

The net energy-balancing hypothesis relating total energy profits and expenditures could primarily explain habitat selection by the study reindeer during winter in these intensively grazed and logged forest areas. In these areas reindeer clearly have a deficit of energy-rich lichens in winter. In our study areas, the availability of both terrestrial and arboreal lichens was best in old growth forests and, therefore, reindeer preferred these forests especially in late winter when grazing conditions were most difficult. In general, it seems also that low elevation forestland has a high winter grazing value for reindeer; however, these same areas are also intensively used by forest industry. This contradiction may become even more problematic in the future, since we assume that especially the use of high elevation forestland pastures may become more difficult for reindeer if global climatic change leads to an increase in winter precipitation.

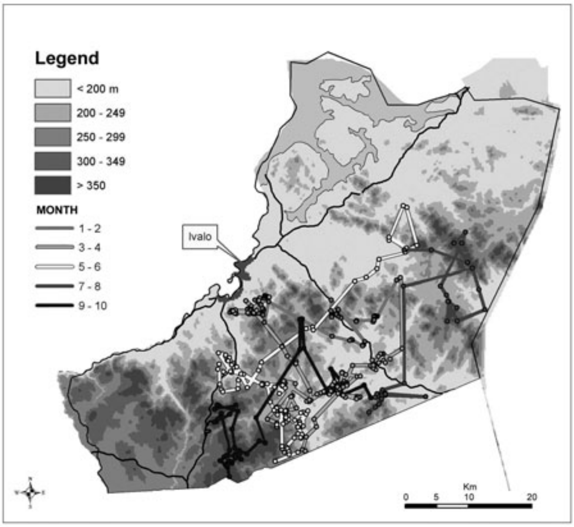

Fig. 12.8 Ten months GPS-track of a reindeer in the Ivalo district

On the basis of our results it is obvious that maintaining a sufficient amount of old growth forest and minimizing linear infrastructure (roads, power lines, snowmobile tracks etc.) in wintering areas of reindeer considerably improves the suitability of these ranges for reindeer herding. However, recent reindeer pasture inventories shows that a great deal of the mature and old growth forest in both of the study districts have been harvested during the period from the beginning of 1970s to the beginning of 2000s. At the same time, lichen pastures have deteriorated markedly mainly due to reindeer grazing.

One of the most important targets for reindeer herding, especially in the northern parts of Finland should be a herding system relying only on natural pastures. This, however, would mean the need for a drastic improvement of winter pastures. To improve winter pastures cooperation between all forms of land use is necessary, forestry management practices have to adjusted, pressure of tourism has to be regulated, but also reindeer herding practices have to evolve. It is clear, that changes in pasture environment of reindeer herding should be understood and accepted as large scale and gradual environmental changes, which are the result of the interaction between geographical and geological conditions, climate and different forms of land use.

12.3 Discussion

The GPS system provides new possibilities for the study of both wildlife and free roaming cattle. Although the first GPS collars were heavy and had engineering problems the present devices are reliable and can be adapted to any type of animal. For research purposes it is highly recommended to conduct a thorough data accuracy assessment, as positional error can exceed the nominal ±15 m (49 ft). The use of differential corrections methods could improve the accuracy to the sub-meter level. Data can be downloaded using VHF-radio or a mobile telephone network (satellite or land based). GPS collars can also be fitted to collect other environmental data, such as temperature, movement, air pressure etc. It could also be possible to equip collars with cameras, microphones and medical monitoring devices.

The present cost of GPS collar equipment ranging from US$ 2000–3000 is still too high for commercial use. A reduction of both the prices and the size of the devices would make it possible for the individual cattle owner to track the whereabouts of his animals, simply by checking his mobile telephone or computer. Comparable devices are already widely in use to track hunting dogs, where a GPS collar with GSM connections transfers data to the hunter who can follow his dog in real time on a map in his GSM-telephone (Tracker Oy, 2009).

Other possible developments of the GPS collar devices could be the use of solar panels to extend battery life, or creating local area networks of small cheap devices to monitor large herds of cattle, keeping track of every individual animal, and using only a few more expensive hubs to relay the data to the owners' computer or mobile device.

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