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Satellite Telemetry in Wildlife Research
Yesterday-Today-Tomorrow

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1. Introduction

For thousands of years Homo sapiens has had the opportunity to observe the migrations and general habits of wild animals, particularly by following their tracks. This was also true for naturalists and wildlife biologists until and including the 20th century. Tracking animals to collect information on their movements is easier in winter when the tracks are clearly visible in the snow. In the summer tracking of wild animals is much more difficult and labor intensive. Hence the development of VHF-telemetry in the 1950`s was a quantum leap in the research of wildlife.

Now it was possible to detect the signals from animals outfitted wilth a transmitter at any time and thus determine their locations. For the first time the behaviour of reclusive or nocturnal animals could be feasibly studied. After some years of development the VHS-transmitters were so small and light that bats and even bees could be outfitted with them (BINNER 1995). However, each position of an animal had to be manually located by cross bearings and the coordinates determined from a map. Later the positions could be determined from automatically operating ground stations (BÖGEL et al. 2002). The range in which animals could be located on land varied between a few hundred meters to a few kilometers (depending on the temperature, humidity, topography, vegetation,etc.). Aerial tracking increased the range of surveillance to the 10's of kilometers. Publications rarely reported on the disturbances caused to the animals studied. Moreover, the accuracy of the locations determined could not be quantitatively ascertained (LEE 1985, SARGEANT 1980, WARNER and ETTER 1983, WEBSTER and BROOKS 1980, WHITE and GARROTT 1990).

2. Satellite Telemetry Yesterday:

Since 1978 the movements of wild animals can be surveyed with the aid of satellites, the researcher became Homo satelliticus. The French Space Ageny and the US National Oceanic and Aeronautics Administration (NOAA) established the **ARGOS Satellite System.** The Argos-satellites localized the signals (frequency and code number) transmitted by an Argos transmitter (also called PTT's – Platform Transmitter Terminals), and sent the data to ground stations which calculated the respective positions and transfered these in turn to the user. The ARGOS-system guarantees a worldwide coverage, though depending upon the latitude, the number of overflights and thus the number of position determinations is limited (6 overflights at the equator and 28 overflights north of 82° latitude, ARGOS 1984). Only one ARGOS-satellite is needed to receive the signals from a PTT, the determination of locations is done by Doppler calculations.

With the ARGOS-Satelllite System the world wide investigations of the ranges, the choice of habitat, and the behaviour of many animal species could be accomplished for the first time: for example, polar bears (KOLTZ et al1980), caribou (CRAIGHEAD and CRAIGHEAD 1986), camels (GRIGG 1987), penguins (LE MAHO 1994) and peregrine falcons (HOWEY 1994). The ARGOS-system is particularly suited to the locating of far ranging animal species because the localizations are only accurate from one to five thousand meters. Caribou of the Porcupine Caribou Herd in Yukon North Alaska, for example, covered up to 5055 km between their summer and winter ranges. The errors in position determination are not significant here. In the beginning the Argos-transmitters were relatively heavy; (CRAIGHEAD and CRAIGHEAD 1987) used ones that weighed 2.1 kg for their investigations of caribou.

In Germany in the early '90's the Argos-system was used especially to investigate the migratory behaviour of birds, for example, BERTHOLD et al (1992) and KAATZ (1995) used it to study the flight behaviour of storks.

3. Satellite Telemetry Today:

In the meantime the accuracy of the Argos-system has clearly improved: depending upon the class of localization values between 100 and 3000 m can be obtained (BRITTEN et al 1999) using transmitters with a weight of 25 g.

Among other animal species or especially in small scale Europe, where even large mammals, for example, red deer often have ranges of only 500 to 2000 ha (GEORGII and SCHRÖDER 1983) position determinations with a variance of less than 100 m are necessary for valid results in studying the movements of wild animals.

The **Global Positioning System** (GPS) provides such accuracy. Since 1994 this system has been available for civilian use at no cost. This satellite system is operated by the US Department of Defense with the objective of localizing any given point on earth with an accuracy of 1 m or less. In principle each of the 36 NAVSTAR satellites permanently transmit various signals that include the transmission time and current position among other information. The GPS-receivers on earth receive these signals and calculate over the time elapsed their distances from the respective satellites. If signals of at least 3 satellites are received simultaneously, then the position of the GPS-receiver can be calculated in 2 dimensions, i.e. its position on earth (HURN 1989).

Another satellite navigation system is operated by the Soviet Glonass. This system, however, is of little importance in wildlife research and so will not be treated further here.

The great efficiency of telemetry using GPS is presented in Fig. 1. Shown are the detected positions connected in chronological order of a female red deer in a low mountain range in Germany. The GPS-receiver recorded its position every hour. The data were then transferred to a geographical information system with thematic maps.

The animal used two ranges during the entire year, and often moved between these through a narrow corridor. The upper range included an area of 1780 ha, the lower 1540 ha (according to MAM). Striking is here the pattern of movement of the red deer: it almost always only wandered to the periphery of its range from a central, nuclear area to which it quickly returned. Longer treks or excursions over several days outside of its "normal" ranges didn't take place.

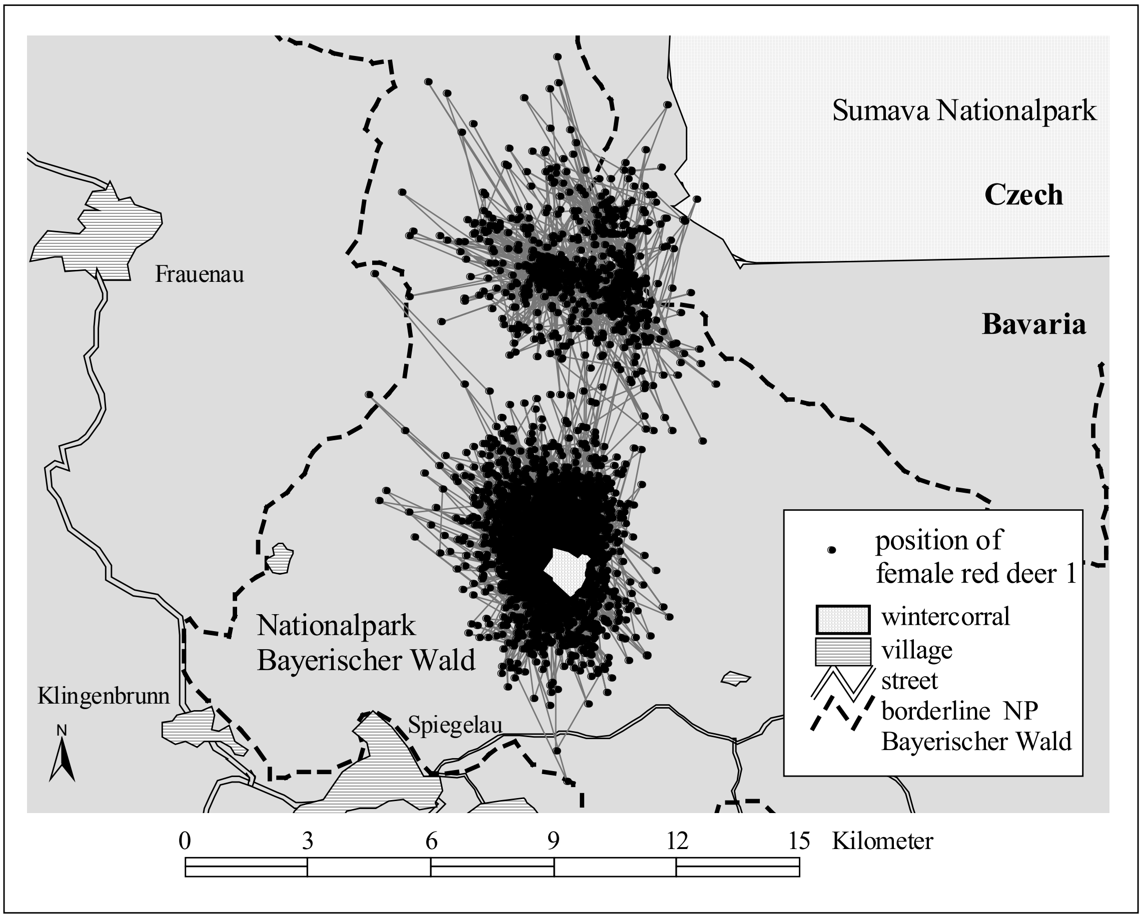

Fig. 1: Locations of a female red deer in Bavarian National Park,
May 2001 – March 2002 (n=6500)

The advantages of telemetry in wildlife research using GPS in comparison to VHF-telemetry are as follows:

1. Several thousand locations can be received and recorded in one collar.
2. The data are automatically and continuously determined.
3. The given time for any position detemination can be freely chosen (even for each single position.
4. The data are digitally immediately availabe to the user and can be evaluated right away.
5. Neither the animals nor the ecosystem are disturbed.
6. Favourable costs of the whole system

The disadvantages of telemetry of wildlife using GPS versus VHF-telemetry:

1. In relation to body mass the GPS-collars are relatively heavy , esp. for mammals.
2. The GPS- collars must be recollected by recapturing the respective animals due to animal protection reasons (exception: “drop-off mechanism)
3. At present no applications in marine biology since GPS doesn’t function under water.
4. Limited use under dense cover, for exanple in rain forests,
5. Occasional problems in data transmission.

For the application in the telemetry of wild animals the GPS-receiver is supplied with additional hard- and software integrated into the collars. Usually a VHF/UHF- transmitter is also included to enable the localization of the animals from the ground or by plane.

In contrast to the PTT ‘s of the Argos-system the GPS-receivers actively determine and record their positions themselves. The GPS-collars on the market record the X, Y, and Z coordinates as well as the date and time of the respective locations. There is the possibility of employing additional sensors to record data on ambient temperature and the activity of the telemetrized animal. In Table 1 various sets of data from a current telemetric study of wolves in Finland are presented.

Table 1: Typical set of data from a GPS-collar from a current study of wolves in Finland

No	UTC Date dd.mm.yyyy	UTC Time hh:mm:ss	ECEF X [m]	ECEF Y [m]	ECEF Z [m]	Latitude [°]	Longitude [°]	Height [m]	Nav	Temp [°C]
1	23.03.2002	14:00:36	2332010	1242281	5785901	65.60024	28.04459	247.16	3D	-17
2	23.03.2002	18:00:41	2332019	1242279	5785894	65.60016	28.04446	244.12	3D	-18
3	23.03.2002	22:00:41	2332014	1242276	5785875	65.60013	28.04446	224.41	3D	-17
4	24.03.2002	02:00:41	2332020	1242275	5785888	65.60014	28.04438	238.24	3D	-19
5	24.03.2002	06:00:41	2332014	1242271	5785887	65.60020	28.04436	234.37	3D	-29

The date and time of the locations are given according to the UTC-System (Universal Time Coordinated). The UTC – Time System is valid worldwide, operating constantly over the entire year. It differs from our MEZ – summer time (Central European Time System) by minus 2 hours, from the MEZ –winter time by minus 1 hour. The values of the coordinates are first drawn up in the ECEF-System (Earth Center Earth Fixed) and then recalculated in latitude and longitude of the WGS 84 System.

The data are normally saved directly “on board” a GPS-collar on a flash memory card, but are not further transmitted. There are various possibilities for the user to access the data:

A. The collar is recollected by recapturing the animal or through the activation of a “drop-off mechanism, and the data are then read through a computer interface.

B. The data are recalled via UHF transmission.

C. The data are momentarily transferred to a ground station via a satellite connection.

D.The data are momentarily transferred to a ground station via radia connection.

To A: The first GPS-collars, marketed ca. 1993 usually provided no possibility to transmit data by radio; to collect the data the animals had to be recaptured. An elegant solution to this problem was the development of the so called “drop-off” mechanism on the collar, an electronic catch that opens the collar. This mechanism is produced by the companies Lotek and Televilt.

To B: The downloading of data via radio is standard for practically all GPS-collars today. The location of the animal in the area of investigation is determined by VHF/UHF–signals and the data are retrieved at a radio station. Howevever, the applications here differ greatly among the producers.

Criteria for the user are: a) the maximum distance the data can be transmitted from the GPS-collar to the radio station (under comparable envrionmental conditions b) the quality of data transmission (are the data completely sent or only part of them c) the time needed for a complete download of data. This is particularly important if the data are downloaded from a plane, as is often necessary in America. The time for downloading depending upon the amount of data transmitted , usually takes between 5 and 15 minutes.

To C: The relaying of data via satellite is offered by the company Telonics, USA , whereby the transmitter of the Argos-Satellite System is used. Currently this telemetric system is particularly employed in the US for studies of large mammals (for ex., www.taiga.net/satellite/index.html), whose habitats are often thousands of kilometers from the next largest town and the costs of downloading data from an airplane are exorbitant (GOLDEN 2001). Further current projects include the telemetric study of elephants in Tanzania (HOFER orally) and of Przewalski wild horses and wolves in Mongolia (WALZER orally).

The use of other satellites in the relaying of data from GPS-collars is also possible. In a pilot project in 1994 the locations of red deer in the Harz Mountains were transferred via the experimental satellite TUBSAT-A to the ground station in Berlin (FIELITZ et al, 1996).

To D: GPS data can be sent directly from the collar via a mobile radio network (GSM Global System for Mobile Communication). A corresponding system was developed by the company VECTRONIC -Aerospace. Here the location coordinates of the animals are momentarily sent by a GSM-modem integrated into the collar, similar to an SMS sent by cell phone. The data are sent dirctly to the user’s office. The prerequisite for the data transmission is that the area of investigation is covered by GSM. This form of data transmission was first tried out in March 2002 on red deer in the Bavarian Forest National Park and on wolves in Finland (www.environmental-studies.de).

Accuracy: The accuracy with which the GPS-receiver determines its position varied between 25 and 80 m up to May 2000. Until then the US Department of Defense purposely decreased the accuracy of locating positions for civilian use (selective availability). Later the selective availability was reduced so that on average an accuracy of 15 m in position determination can be achieved.

The accuracy of the measurement can be clearly improved by a differential GPS. There are two possibilities: a modem receiving corrected data from a reference station whose exact location is known is integrated into the GPS-collar and these data are included in the calculation of its own position. This improves the accuracy to 4 – 8 m. A further possibility is to record data error via satellite orbits and to correct them by the so called "post processing" with the determined GPS-position. The attainable accuracy with this method is within the 1 m and less range, depending upon the work involved. Differential GPS is optionally offered for GPS-collars by some producers such as Lotek and Televilt. The user should thoroughly evaluate how accurate his localizations must be to attain the goals of his research. How accurate are the maps used for data evaluation, for example?

Collar weight and number of positions: The GPS-collars produced in 1994 weighed about 1400 g and could record a maximum of 800 positions. Now in the year 2002 the GPS-collars with the greatest capacity have a total weight of 505 g and can record up to 8000 positions (worst case calculation). One producer, Televilt offers a GPS-collar that weighs only 80 g and can record at most 450 positions. Data transmission via radio is not possible with this instrument, the programming and the reading of the data are conducted by the company. The company VECTRONIC-Aerospace has developed a 250 g model that can record 1500 positions, and the data can be retrieved with a UHV-modem.

The weight of the collars is mainly due to the weight of the batteries along with the other hardware components (collar material, castings, etc.). The GPS-receiver only weighs 5 – 10 g. The number of batteries needed depends on the capacity and the electricity consumption of the electronic systems whereby the GPS-receiver alone uses 95%.

The electricity consumption of the GPS-receivers depends on how much time is required to determine a position and how much time is maximally allotted for this ("GPS on time"). For a valid 2D localization the signals of at least 3 satellites, for a 3D localization the signals of at least 4 satellites must be simultaneously received. Depending on the external conditions (terrain topography, shading of the GPS-collar by dense vegetation, for ex.,) a great amount of time may elapse. Subsequently, the system goes into a very low energy use phase until the next position can be ascertained. If the positions are recorded in close intervals, the next localization is completed more quickly than with long intervals because the GPS-receiver needs less time to renew its information from the satellite.

Fig. 2 shows a histogram for the time a GPS-receiver needed to find and record the location of a female red deer during a 10 month telemetric study in the Bavarian Forest National Park. 6500 positions were evaluated. 95% of the locations were determined in less than 135 seconds; the average determination took 51 seconds.

In order to compare the capacities of different GPS-collars, the position calculation method the producer uses must be known, especially what time period is allotted for the "GPS on time" (common value = 90 sec). Then it is important to know whether the number of localizations were calculated according to a "worst case calculation", i.e. whether the number given corresponds to that which the GPS-receiver can achieve at defined conditions (for ex., 0°C ambient temperature); or whether the calculations were done for optimal conditions giving the maximum number of positions.

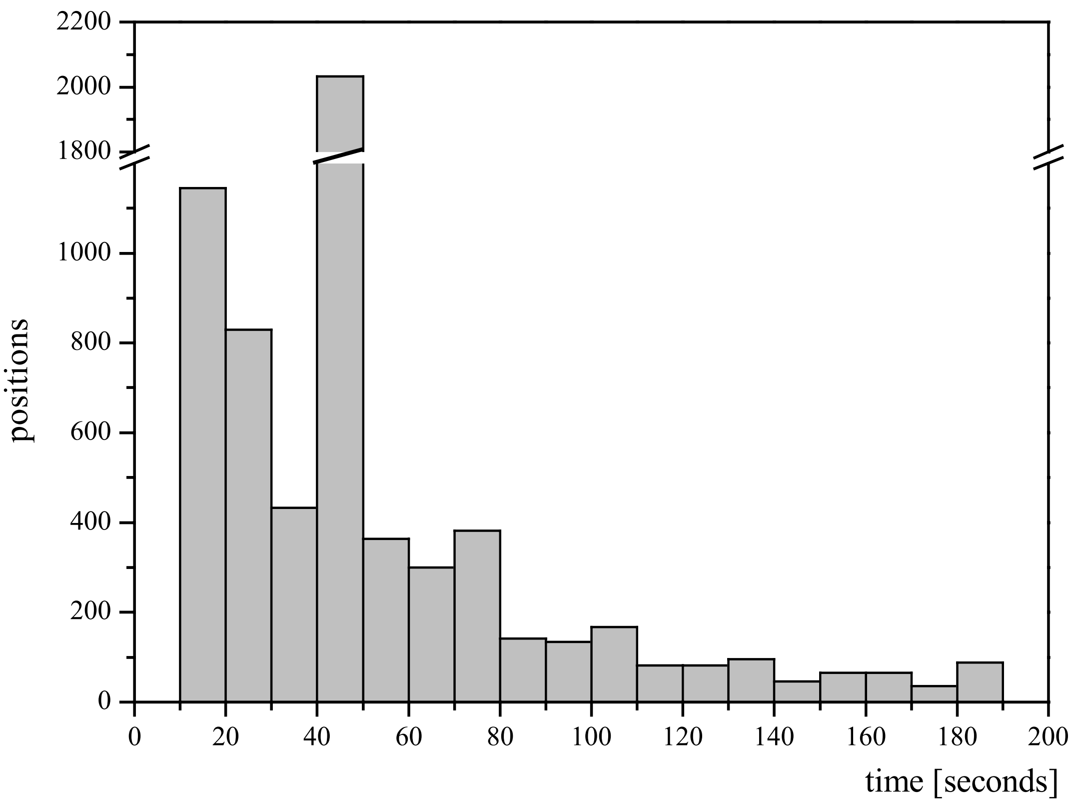

Fig. 2: Time periods the GPS-receiver needed to locate and record locations of a female red deer in the Bavarian Forest National Park

4. Satellite Telemetry Tomorrow

The future will provide the users with a further satellite navigation system: Galileo. The European Union will completely install the necessary satellites by the year 2008 and operate the system. Galileo is being developed so that Europe will have its own satellite navigation system and be independent of GPS as the US Dept.of Defense can in crisis situations cut off use by other nations at any time. With Galileo the accuracy of position determination will be further increased to less than 5 m..

In general satellite telemetry will in future provide the user with more data, smaller instruments, and a better data transmission.

More data means that in about 5 years a 500 g GPS-collar (with download possibilities) can record upto 100000 positions. This will make it possible to exactly determine the ranges of wild animals, to conduct extensive habitat studies, as well as to investigate hunter-prey systems and other complex interrelationships within and between species as is not imaginable at present. The integration of optical sensors will improve this prospect. For the first time it will be possible to monitor the biographies of individual wild animals over the long term.

Smaller and lighter GPS-collars will be available, with weights of under 150 g with capacities of determining thousands of positions (worst case calculation). This will be made possible by the reduced electricity consumption of the GPS-receivers and more powerful batteries.

Data transmission will also be more convenient. Downloading will take place in 10's of seconds. Furthermore the relaying of data via the mobile telephone system using new formats such as the UMTS, for example, will be able to transmit greater quanities of information faster.

5. Summary

The telemetry of wildlife with the aid of satellites has been possible since 1978 with the advent of the Argos-system, with which countless studies have already been conducted worldwide. The Argos-receiver is available in a weight of 10 g and can therefore be used for onithological studies. The positions are transferred directly to the user via a ground station. However, the error with which a position is determined is between 100 and 3000 m.

The Global Positioning System (GPS), available for civilian use since 1994, permits determination of positions with an average of 15 m accuracy, whereby with the corresponding correctional calculations an accuracy of 1 m and less can be achieved. For the telemetric studies of wild animals GPS-receivers with special electronics are integrated into a collar and the determined positions recorded there. Several possibilites exist to retrieve this data: recollection of the collar and retrieval and transmission of data via radio, satellite, or mobile phone. The GPS-System at present enables the user to record ca. 8000 positions in a collar weighing 550 g. The lightest instruments weigh less than 100 g, however, they are only able to record a limited number of positions.

In future GPS-collars will become smaller, lighter, and have a greater capacity. In the year 2007 a 500 g collar should be able to record 100000 positions. Collars lighter than 150 g with the option of recording several thousand positions will enable researchers to study middle sized wild animals. Special sensors will be developed that permit spectacular insights into the lives of animals.

After the year 2008 a further satellite system. Galileo, permitting even exacter localizations, will become available to the user.

Zusammenfassung

Die Telemetrie von Wildtieren mit Hilfe von Satelliten ist seit 1978 mit dem Argos-System möglich, mit dem weltweit unzählige Studien durchgeführt wurden. Die Argossender sind mit einem Gewicht ab 10 g sehr leicht und bieten eine Anwendung, auch in der Ornithologie. Die Positionen werden über Bodenstationen direkt an den Anwender übermittelt. Allerdings liegt der Fehler, mit dem eine Position bestimmt wird, zwischen 100 und 3000 Meter.

Das Global Positioning System (GPS), seit 1994 für die zivile Nutzung verfügbar, erlaubt Positionsbestimmungen von durchschnittlich 15 Metern Genauigkeit, wobei durch spezielle Korrekturrechnungen Werte im Meter und Submeterberich errreicht werden kann. Für die Telemetrie von Wildtieren werden GPS-Empfänger mit spezieller Elektronik in ein Halsband integriert und die ermittelten Positionen dort abgespeichert. Um an die Daten zu gelangen, bestehen mehrere Möglichkeiten: Rückgewinnung des Halsbandes und Auslesen der Daten, Datenübertragung via Funkstrecke, Satellit oder Mobilfunknetz. Das GPS-System ermöglicht dem Anwender 2002 die Aufnahme von rund 8000 Positionen bei Halsbandgewichten von

550 g. Die leichtesten Geräte wiegen unter 100 g, allerdings mit eingeschränkter Aufnahme von Positionen.

Zukünftig werden GPS-Halsbandsender deutlich kleiner, leichter und leistungsfähiger sein. Im Jahr 2007 werden mit 500 g leichten Halsbändern etwa 100.000 Positionen aufgenommen werden. Halsbänder, leichter als 150 g, mit der Option auf mehrere tausend Positionen werden die Telemetrie von kleineren Säugetierarten ermöglichen. Spezielle Sensoren werden hinzukommen, die spektakuläre Einblicke in die Lebensweise von Tieren ermöglich werden.

Ab 2008 wird dem Nutzer mit Galileo ein weiteres Satellitensystem zu Verfügung stehen, das eine genauere Lokalisation ermöglicht.

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