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ORIGINAL ARTICLE

Recording movement and activity pattern of a White-tailed Sea Eagle (*Haliaeetus albicilla*) by a GPS datalogger

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Abstract For the first time, we measured the home range size and activity pattern of a White-tailed Sea Eagle (WTSE) by GPS telemetry. Positions were recorded three times a day and the activity pattern were continuously recorded by two acceleration sensors. From July to January, we obtained 475 positions and calculated a 95% kernel home range of 4.53 km^2 and a 95% minimum convex polygon of 8.22 km^2, indicating a rather small area explained by an optimal habitat and by the much more precise location method used here compared to reports in the literature. Biorhythmic analysis of activity data revealed nearly no night-activity, high day-activity with no fixed daily pattern and a strong 24-h period of activity. The stability and synchronisation between the eagle's activity and the environmental 24-h period was evaluated by calculating the degrees of functional coupling (DFC) and the harmonic part (HP). Mostly, DFC was 100% (meaning that the different physiological and behavioural functions are completely synchronised to each other and to the environmental 24-h period) and the few incursions of the DFC we assumed to be caused by clinically relevant lead intoxications. The agonal stage of the WTSE was indicated by a daily decreasing activity level and HPs and highly modified day–night relationship, and decreasing DFCs at the beginning and at the end of dying process, representing changes in the activity structure. The underlying reason for the behavioural changes was found to be a lethal lead intoxication due to an oral ingestion of particles of rifle ammunition. The new technology of a combined GPS receiver and an acceleration sensor allows the automatic measuring of positions and activity of wild animals at a very precise level over prolonged periods which cannot be achieved by manpower.

Keywords Telemetry · Lead intoxication · Hunting ammunition · Activity · Stress detection

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Introduction

Very little is known about the home range size and the activity pattern of the threatened White-tailed Sea Eagle (*Haliaeetus albicilla*) (WTSE) throughout its range. The few studies on the home range size are based on estimations and visual observations. In earlier times, large movements were assumed to be normal for the eagles; thus, hunting flights of 35 km have been observed (Kuhk 1927). Fischer (1959) estimated the home range of WTSEs in the Mecklenburg region to be 24–36 km^2. Oehme (1975) assessed the hunting area of the WTSE in the Mecklenburg Lake Plateau District and the Baltic coast to be between 12 and 65 km^2. He indicated the hunting territory of 30 intensively studied pairs in different regions of Mecklenburg to be 12–40 km^2, with the majority being 20–30 km^2. He measured the radius from the nest to be 3–14 km, but stated that distances above 10 km were rare. Looft and Neumann (1981) assumed the year-round home range of WTSEs in Schleswig-Holstein to be not smaller than 100 km^2. Brüll (1984) proposed an area of 60–120 km^2 that a WTSE pair needed to reproduce. Struwe-Juhl (2000) estimated the home range of ten WTSE pairs during the breeding period in Schleswig-Holstein, Northern Germany, using synchronised field observations aided by walkie-talkies, to be 61 km^2 on average, ranging from 19 to 115 km^2.

Activity patterns of WTSEs have been studied on several occasions by visible observation, but not in the detail which was possible with the technique described here. Generally, the eagle is diurnal, with longer activity periods during summer and shorter periods during winter time. In summer, the eagle starts being active on average 44 min before sunrise and reaches the night roost on average 11 min before sunset (Willgohs 1961). During the winter, the eagles get active much later than sunrise and are already starting to perch for the night in the late afternoon, having their main activity during the late morning and early afternoon (Glutz von Blotzheim et al. 1971). By analysing the time structure of continuously measured activity data, it is possible to describe the normal daily and seasonal activity and to detect inconspicuous changes in the activity pattern over a prolonged period. Reasons for such changes may be the animals' adaptation to seasonal varying environmental conditions, but also changes due to disturbances caused by external stimuli or stressors, resulting in a lower level of synchronisation of activity and circadian rhythm (Berger et al. 2003). Here, we were able to test a new system which combined an automatic GPS receiver and a very sensitive automatic acceleration sensor. The aims of this study were to: (1) calculate the home range, and (2) to record the activity pattern of an adult wild WTSE.

Methods

Study area

Our study area is part of the protected natural park Nossentiner/Schwinzer Heide in Mecklenburg-Western Pomerania, in Northern Germany (53°30′–53°40′N, 11°59′–12°35′E). The landscape formed during the Weichsel glacial period is characterised by more than 60 freshwater lakes covering 13% of the area, secondary forests (60%) dominated by Scots pine (*Pinus sylvestris*), and agriculture (20%). In this protected landscape of 365 km^2, 15 breeding pairs of the WTSE form one of the highest densities of this species in Northern Germany.

Data recording

The female WTSE was caught on a freshwater lake using a modified noosed fish method of Robards described by Frenzel and Anthony (1982). We equipped the eagle with a datalogger (bird pro®, made by Vectronic Aerospace, Berlin) on 24 July 2003. No offspring was raised in 2003. The datalogger consists of a GPS receiver, a VHF beacon, a UHF link, a temperature sensor and two acceleration sensors orientated in longitudinal and transversal directions (Fig. 1). We programmed the GPS receiver to get three positions a day, the first 1 h following sunrise, the second 1 h later and the third position 1 h prior to sunset. Battery capacity was calculated to last for 1,000 positions. The data (GPS-positions and activity) were downloaded from the logger every 4–6 weeks by using a handheld UHF receiver. An 18-h test of the GPS receiver revealed very precise positions ($n = 216$) of an average value of 52.43086 ± 0.00006°N and 13.52578 ± 0.00007°E, which means with an error of only 3.96 m longitudinally and 7.79 m latitudinally, respectively.

For activity measurement, the accelerations of the forward/backward direction and the left/right direction were recorded eight times per second by the two axis accelerometer with a range of ±2,000th of the acceleration of gravity (~0.02 m/s^2). The differences between two sequenced measurements were accumulated and scaled over the recording interval of 5 min. The result is a value between 0 and 255 for each axis. A value of 0 means no or very low activity and 255 means a very high activity. By using the UHF link, the position, temperature, and acceleration values of the bird were frequently downloaded using a hand-held terminal.

The VHF beacon was active from 06:00 to 18:00 hours. The weight of the transmitter was 170 g amounting 3.5% of the body weight of the WTSE (4.9 kg).When captured, just a colour ring (silver above black) was present on the bird while the ring of the national ringing station with an individual number was missing. This particular colour ring of the International White-tailed Sea Eagle Colour Ring Scheme Program (Helander 2003) was used in 1991 for

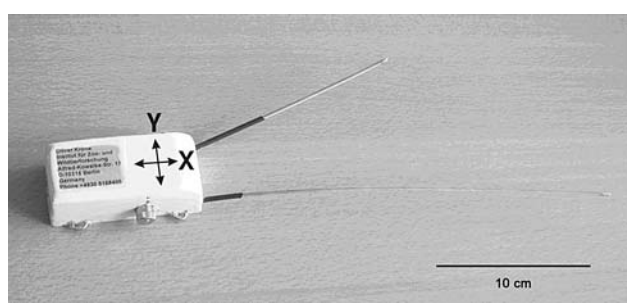

Fig. 1 Shape and size of the datalogger. The two axes of the acceleration sensors are projected on the device. The long antenna emits VHF signals and the short antenna UHF signals for the download. An address label is attached to increase the recovery of the datalogger

nestlings of WTSEs in Europe, indicating that our bird was 12 years old (13th calendar year).

The datalogger was attached as backpack using a harness made of Teflon ribbons. We applied a fitting that allowed the transmitter to move 1.0 cm forewards and backwards on the bird's back. When pulling on the backpack it could be lifted 0.5 cm which corresponds with the snug fitting described by Buehler and Fraser (1995). The four ribbons were sutured together above the sternum forming a predetermined breaking point (Kenward 2001).

Data analysis

Calculations of the home range size were made in ArcView GIS 3.3 (ESRI) with the extension Animal Movement SAv2.04 beta (Hooge and Eichenlaub 2000). Winter season was defined from 23 September to 21 March and summer vice versa. The home range size was calculated using two standard methods: the minimum convex polygon and the kernel method. The kernel home range calculates a fixed kernel home range utilisation distribution (Worton 1987) as a grid coverage using the least squares cross validation (LSCV) (Silverman 1986) as smoothing parameter.

For activity analysis, the data of the two acceleration sensors were summarised and plotted as classical actograms. They show the activity coded in greyscales in daily records which are displayed one beneath the other. Activity data of 1 day were averaged to daily means and activity data of 1 month were averaged to monthly mean activity. In the same way, the daily and monthly day–night activity relationships were calculated: they can vary between 1 (no activity at night) and −1 (no activity at day). The actual daylight hours were drawn from Ahnert's astronomic table (Burkhardt et al. 1994). We also computed the acrophase and the amplitude of the approximated 24-h sinus function using the cosinor method obtaining the time and the intensity of the main daily activity phase (Halberg et al. 1967). The degree of functional coupling (DFC) was as published by Scheibe et al. (1999) and the harmonic part (HP) we calculated as described in Berger et al. (2003) to detect and evaluate stress conditions. The HP is equivalent to the total intensity of all harmonic rhythmic components of activity behaviour and the DFC expresses the relationship between the HP and all rhythmic components in activity behaviour no matter whether it is harmonic or non-harmonic. DFC and HP are high in well adapted, healthy and undisturbed individuals, but low during periods of adaptation, sickness or social interactions (Berger et al. 2003). DFC varies between 100% (maximum of rhythmic harmony within the organism and its environmental 24-h period) and 0% (total disharmony).

Results

Movements

From the day of releasing the eagle (24 July 2003) until its death (14 January 2004), 475 GPS positions were recorded during 173 days. In 44 (8.5%) cases, the datalogger was not able to record a position.

The calculated home range using the minimum convex polygon method (100%MCP) was 48.47 km^2 including single excursions to the periphery. Removing 5% of all outlier positions using the harmonic mean method results in a 95%MCP of 8.22 km^2. More detailed kernel and MCP calculated home range sizes are shown in Table 1.

The death of the eagle was detected at the end of January 2004 during a standard data download. The death was indicated by the dropping of the temperature down to the ambient temperature, missing acceleration values (Fig. 2) and successive positions from exact the same place on an island in the lake.

Cause of death

As soon as the environmental conditions (melting of the ice layer on the lake) allowed, the eagle carcass was collected and brought to the Leibniz Institute for Zoo and Wildlife Research for a detailed post-mortem examination. A radiograph prior to the necropsy revealed two metallic fragments in the oesophagus. After opening the moderately autolytic carcass all internal organs were still present. No fat tissue could be detected and neither the oesophagus (crop) nor the gizzard contained food items. The liver was swollen, and the gall bladder and the bile ducts were enlarged. No other pathological findings were recorded. Tissue samples taken for histo-pathological examination showed an advanced autolysis. Kidney and liver samples were examined for heavy metals at the Research Institute of Wildlife Ecology, Vienna, Austria. Lead values of 15.60 ppm (wet weight) in the liver and 7.352 ppm (ww) in the kidney

Table 1 Kernel and minimum convex polygon (MCP) home range sizes (km^2) of the White-tailed Sea Eagle (*Haliaeetus albicilla*)

	Observation period	Winter	Summer
95% kernel	4.53	6.61	2.33
75% kernel	1.34	1.96	0.81
50% kernel	0.50	0.59	0.37
LSCV	279.94	343.66	200.06
95% MCP	8.22	15.24	3.83
100% MCP	48.47	48.28	4.30
Number of positions	475	305	170

Values of the least square cross validation (LSCV) are indicated

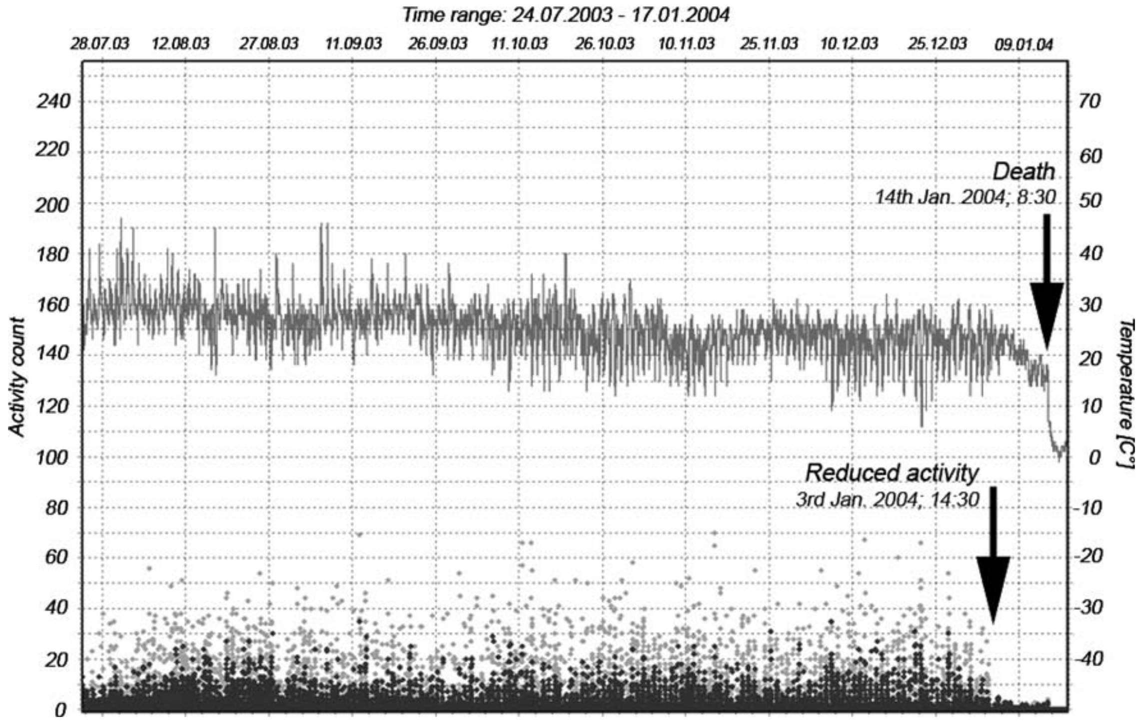

Fig. 2 Activity data (*black* and *grey dots*) and temperature (*grey line*) of the White-tailed Sea Eagle (*Haliaeetus albicilla*) during the time of observation by the datalogger (24 July 2003 to 14 January 2004)

revealed lethal concentrations (Franson 1996). A detailed analysis of the recorded activity and position data allowed us to define the time of death to the nearest 5 min. Eleven days before the eagle died it flew to a small island. During its last days, from 3 January until death on 14 January, the eagle did not leave the small island where it was finally found and had reduced any activity to a minimum.

Activity

Activity data of WTSE were analysed for the whole measuring period of 174 days. The general activity corresponded with varying sunrise and sunset times (civil dusk and dawn) and is relatively evenly distributed during the day time. The low activity during the night (with day–night relationships from 0.88 to 0.95) is obvious in this day-active raptor. The activity was severely reduced after 4 January 2004, just before its death. A clear daily pattern (for instance peaks around twilight hours) is not visible (Fig. 3).

The total average of daily mean activity was 33.1% with a clear maximum in August (50%), whereas the monthly mean activity dropped from 36.4% in December 2003 to 4.5% in January 2004 (Table 2). The monthly acrophase of activity varied between 11:57 and 13:29 hours with the highest amplitude of nearly 57% in November and December and the lowest amplitude in January (6%), the month of its death (Table 2). The monthly DFCs were always at the maximum of 100% except for the November 2003 with a monthly DFC of 94%. In contrast, the monthly HP was highest in November 2003 (20.3%) and lowest in September 2003 (8%) (Table 2).

The daily DFCs were usually at the maximum of 100% (Fig. 4), with some incursions which occur from 29 August 2003 to 3 September 2003, on 19 September 2003, on 19 October 2003, on 23 October 2003, from 23 to 25 November 2003, on 27 November 2003, from 25 to 27 December 2003 and on 7 January 2004. During these decreases of DFCs, an increase of mean activity has mostly been noted. The daily HPs oscillated during the investigation, whereas the level of oscillating HPs switched at the end of October to a higher value.

There was a clear decrease of daily mean activity and of daily HPs combined with extremely oscillations of day–night relationships after 25 December 2003. At the same time (from 25 December 2003 to 14 January 2004, the death of the eagle), the DFCs were 100% (with one incursion on 7 January 2004 of 65.1%) or not calculable due to the low level of activity.

Discussion

Movement

For the first time, the home range of a WTSE was recorded, by using the Global Positioning System (GPS), from July

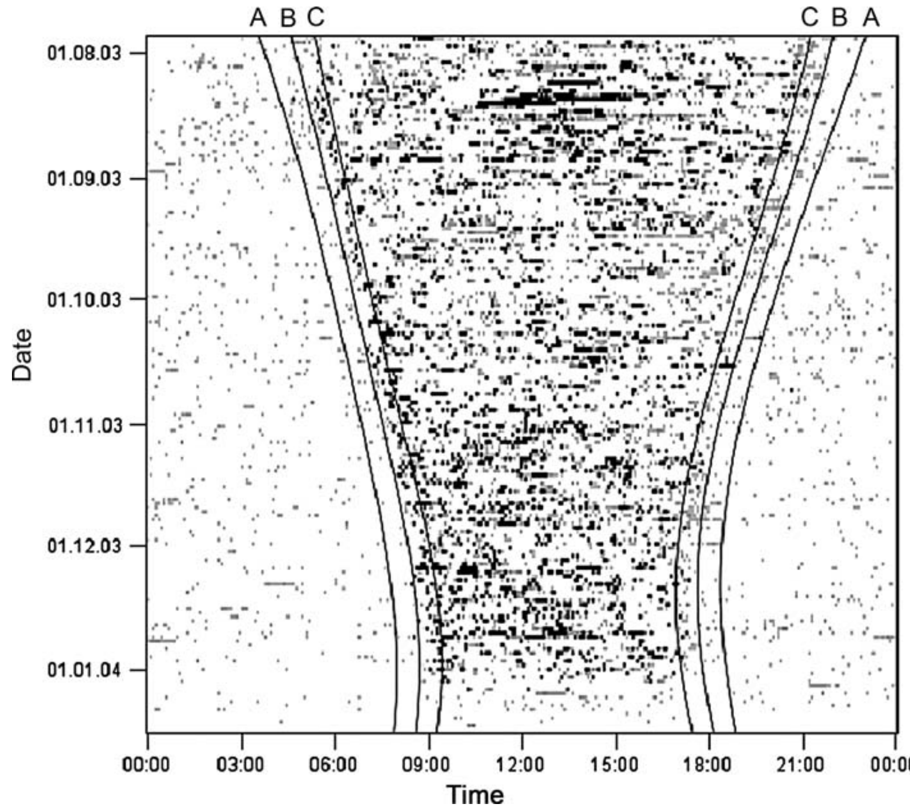

Fig. 3 Activity plot of the female White-tailed Sea Eagle from 27 July 2003 to its death on 14 January 2004. High activity is characterised by *black dots*. Sunrise and sunset is indicated by *black lines* (*A* nautical dusk and dawn, 102°; *B* civil dusk and dawn, 96°; *C* official sunrise and sunset, 90°)

Table 2 Monthly variation of acrophase and amplitude of the 24-h period, mean activity level, day–night relation, degrees of functional coupling (DFC) and harmonic part (HP) of a female White-tailed Sea Eagle from July 2003 to its death in January 2004

	Results of cosinor method						Mean activity (%)		Day:night relation		DFC (%)	HP (%)
	Acrophase (time)			Amplitude (%)								
		From	To		From	To		SD		SD		
Jul 2008	11:57	10:05	13:48	37.5	22.2	52.8	35.5	13.2	0.96	0.02	–[a]	–[a]
Aug 2003	13:22	12:58	13:46	50.4	45.2	55.6	50.0	21.2	0.89	0.08	100	12.0
Sep 2003	12:47	12:16	13:47	34.2	29.8	38.7	31.7	14.9	0.90	0.05	100	8.0
Oct 2003	12:32	12:06	12:59	44.3	39.3	49.4	34.8	15.7	0.90	0.11	100	10.7
Nov 2003	12:35	12:16	12:54	56.8	52.1	61.5	38.4	14.5	0.94	0.05	94	20.3
Dec 2003	12:35	12:15	12:55	56.9	51.9	61.8	36.4	16.2	0.96	0.03	100	19.6
Jan 2004	13:29	12:11	14:47	6.0	4.2	7.9	4.5	5.7	0.46	0.53	–[a]	–[a]

[a] No calculation was done because of incomplete monthly data set

2003 to January 2004. With these precise positions, the home range was measured and revealed a much smaller area of 4.5 km^2 (95% kernel observation period) than known from visual field observations (Brüll 1984; Looft and Neumann 1981; Oehme 1975; Struwe-Juhl 2000). The study area (natural park Nossentiner/Schwinzer Heide) where the eagle was equipped with the device belongs to the Mecklenburg Lake Plateau District, a core area of the Middle European WTSE population where WTSEs breed in high densities with more than 15 breeding pairs on 365 km^2. The Mecklenburg Lake Plateau District is characterised by hundreds of freshwater lakes and large pine forests with old trees sufficient for nesting, indicating a high quality habitat for the WTSE. In our case, the eagle's home range included a shallow eutrophic freshwater lake with a high number of cyprinid fish. Therefore, the data may reflect a small home range size in an optimal habitat type of the WTSE in Middle Europe.

The high number of recorded positions ($n = 475$) result in a much more precise picture of the habitat size of the

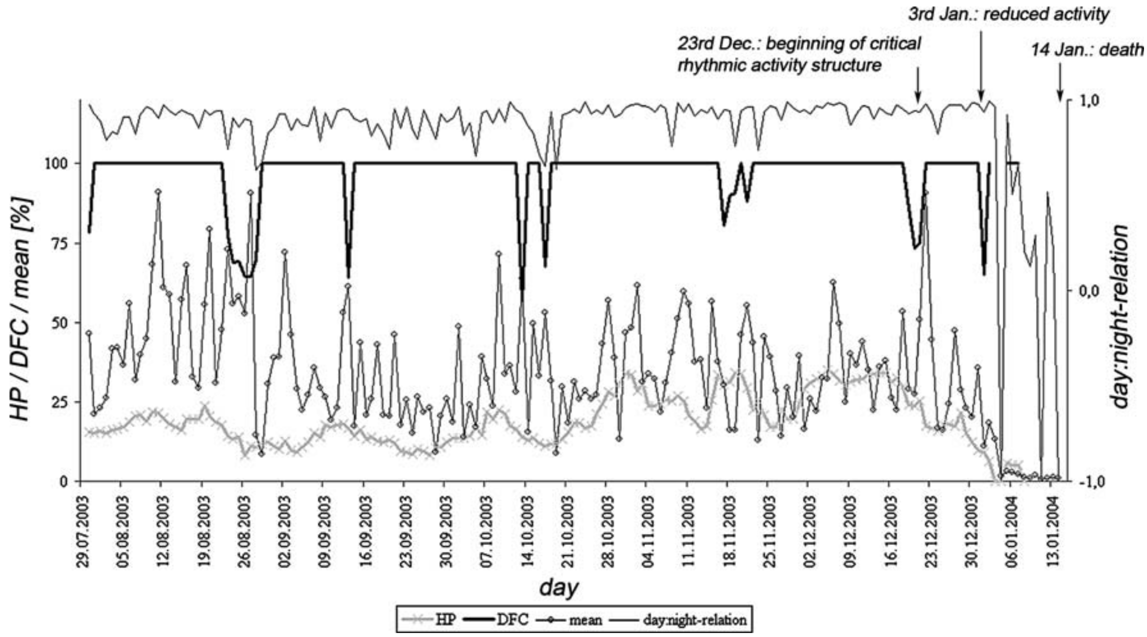

Fig. 4 Degrees of functional coupling (DFCs) (*fat black line*), harmonic parts (HPs) (*fat grey line*), mean day-activity (*fine black line*) and the day–night relationship (*dotted line*) of the female White-tailed Sea Eagle from 29 July 2003 to its death on 14 January 2004

WTSE than visual observations which themselves may influence the results by the observers being present in the home range of the WTSE. However, the period of recording the home range was only half a year, but included the autumn and half of the winter. Maybe excursions at the end of the winter could have extended the area. In general, the eagle had a very small home rage, using only a wedge-shaped piece of the lake but a large area of the forest. Within the home range, the eagle preferred borderlines, i.e. forest edges at the strand, at reforestations and at grassland. However, the small home range size of the WTSE may have various implications for the protection of this species and for the identification of potential threats (e.g. poisoning). It is very likely that the eagle has acquired the lethal lead intoxication within the small home range where local hunters have left the gut piles of game animals. Hence, local hunting practice has direct consequences for the potential death of scavenging birds in the area. The unexpected death of the WTSE brought the data collection by the GPS datalogger to an abrupt end. Nevertheless, the cause of mortality is not wholly surprising since lead intoxication is the most important cause of death in WTSEs from Germany (Krone et al. 2003). In our case, the datalogger recorded the course of the lead intoxication of the eagle in 5-min intervals regarding any activity and three times a day by GPS positions. These data revealed that the eagle flew to a small island in the freshwater lake where it remained for 11 days until death. The acceleration sensors recorded only very low activities during the last days of life supporting the GPS data which indicated no flight activity.

Activity

In this study, we were able to measure the activity of a WTSE continuously over a period of 6 months in its natural habitat. There is nearly no activity during the night while the daily activity during daylight hours fluctuates considerably from day to day, which is most likely due to weather influences whereas wind and rainfall are the most important to eagles (flying) activity. Activity bursts during the midday hours in August and during dawn in autumn may be correlated with times of updrafts.

The distinct day–night behaviour has shaped a remarkably stable activity structure: the acrophase of the 24-h period was situated around midday during all months, the dominating frequency of the power spectrum was always the 24-h period and the DFCs mostly were at the maximum near 100%.

Stable rhythmic patterns have been described as basic precondition for animal welfare, and numerous observers have described more or less identical time patterns of behaviour from day to day in stress-free conditions (e.g. Mayes and Duncan 1986). Impairment of phase relations, changes in frequency structure, loss of rhythmicity or reduction of amplitude are regarded as signs of adaptation, disease or premortal state (Veissier et al. 1989; Minors et al. 1996; Weinert 2000).

The remarkable predominance of the 24-h component in the activity rhythm of WTSE mostly resulted in maximum DFCs of 100%. On several occasions, we could find temporary structural changes in activity of the WTSE consisting of reduced DFCs and decreasing HPs indicating behavioural problems of the bird. Stresses caused by direct human activity (hunting, tourism, etc.) or neural disorders (i.e. clinical lead intoxication) could be possible causes of these disturbances. Considering the cause of death due to an oral ingestion of lead particles from a rifle bullet we assume a repeated uptake of lead resulting in clinical intoxications associated with the described changes in frequency structure of activity (Franson 1996). These may correlate with increased human game hunting activities in autumn. During these times, access to fish is reduced and gut piles of shot game animals are usually left in the field constituting an easily accessible protein source.

The premortal stage of the WTSE started on 23 December indicated by daily decreasing activity level and HPs and highly modified day–night relationships. The DFCs dropped at the beginning and at the end of dying process, representing changes in the activity structure. These alterations correspond completely with those of sheep with a deadly parasitic infection (Berger et al. 2003). Especially, long-term changes of the normal activity may easily be detected by analysing the DFCs and HPs in diseased animals.

Conclusions

The automated continuously and long-term recording of the activity of a WTSE proved to be an appropriate approach for describing the general behaviour and seasonal, species-specific variation, for detecting disturbing conditions and for identifying behavioural alterations of clinical relevance. This new technology offers an outstanding method to measure the activity at a very precise level over prolonged periods, which cannot be achieved by manpower. The GPS device used here is characterised by positions with a high precision, processes large datasets and costs of operation are very low, but the weight should be reduced in further applications. The lethal lead intoxication of the eagle due to an oral ingestion of lead particles from rifle ammunition could be demonstrated, movement and activity patterns were traced and analysed until death. The small home range size emphasis the local relatedness of lead intoxications. The use of lead containing ammunitions for hunting game animals poses a severe threat for all scavenging birds and should therefore be prohibited.

We think that this technology may also help identifying the threats of other endangered species by combining precise position with short interval activity data.

Zusammenfassung

Automatische Aufzeichnung des Bewegungs- und Aktivitätsmusters eines adulten Seeadlers (*Haliaeetus albicilla*) mittels GPS-Datenlogger

Erstmalig wurde ein Seeadler mit einem GPS-Datenlogger besendert und die Größe seines Aktionsraumes und sein Aktivitätsmuster bestimmt. In der Zeit von Juli 2003 bis Januar 2004 wurde drei Mal täglich die Position des Adlers registriert und die Aktivität kontinuierlich mittels zweier im Sender integrierter Bewegungssensoren aufgezeichnet. Insgesamt wurden 475 Ortungen vorgenommen. Der berechnete 95% Kernel Aktionsraum betrug 4,53 km^2 und das 95% Minimum Konvex Polygon 8,22 km^2 deuten (im Vergleich zu früheren Literaturangaben) eher auf einen kleinen Lebensraum hin, was möglicherweise an einem optimalen Lebensraum und sehr präzisen Positionsdaten liegt. Der Seeadler zeigte fast keine Nachtaktivität, eine hohe Tagesaktivität ohne festgelegte Tagesmuster und eine sehr deutliche 24-Stunden Aktivitätsrhythmik. Die Stabilität und Synchronisation zwischen der Aktivität des Adlers und der 24-Stunden-Umweltperiodik wurde anhand von „Leistungsbezogenen-Kopplungsgraden" (DFC) und „Harmonischen Anteilen" (HP) berechnet. Dabei betrug der Grad der Kopplung nahezu 100%, was bedeutet, dass die verschiedenen physiologischen und verhaltensbiologischen Funktionen vollständig zu einander und zur äußeren 24-Stunden Periodik synchronisiert sind. Die wenigen Einbrüche der DFC sind vermutlich auf klinisch relevante Bleiintoxikationen zurück zu führen. So wurde die Agonie des Seeadlers durch eine abnehmende Tagesaktivität, einen Rückgang der „Harmonischen Anteile", einem deutlich veränderten Tag-Nacht-Rhythmus und Einbrüchen der DFC angezeigt. Als Grund für die Verhaltensänderung wurde eine letale Bleivergiftung pathologisch und toxikologisch identifiziert, die auf die Aufnahme von Resten bleihaltiger Büchsenmunition zurückgeführt werden konnte. Die hier verwendete, neue Technik eines kombinierten GPS-Empfängers mit integrierten Bewegungssensoren ermöglicht die automatische Messung von Positionen und Aktivitäten von Wildtieren auf einem sehr präzisen Niveau über einen längeren Zeitraum, welches allein durch Feldarbeit nicht möglich ist.

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