Acceleration derived feral cat (*Felis catus*) behaviour during ground nesting bird-breeding season on the island of Schiermonnikoog

(Wilson, 2014)

Research Paper Bachelor Thesis

Hogeschool VHL University of Applied Sciences

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Animal Management, Major Wildlife Management

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Abstract

Due to their high adaptability and opportunistic predation behaviour feral cats have a great impact on worldwide bird biodiversity in particular on islands. However not much is known about their actual behaviour and time budget, as direct behavioural observations often are difficult regarding free-ranging animals that live in remote areas. Since knowledge of behaviour is essential for effective management this study aimed to get insight into feral cat behaviour and behavioural time budgets. On the island Schiermonnikoog in the Dutch Wadden Sea, which represents an important area for breeding birds, nine feral cats were collared with tri-axial accelerometers, which measured acceleration for a period of three months during the breeding season of ground nesting birds in 2014. In order to link the recorded acceleration data to actual behaviour supervised classification was used. In October and November 2014 video footage of the feral cats was obtained and linked to the acceleration data. In total this training dataset comprised 5805 seconds containing fixed 1 s segments of single feral cat behaviour. By means of a Random Forest model using 15 summary statistics and executed with the web-based application AcceleRater feral cat behaviour was labelled to acceleration data. The model was validated by a 10-fold cross-validation. In total 10 behaviours were classified with an overall performance of 84 %. Regarding the circadian cycle, the feral cats were most active during 22:00 - 01:00 h. Lying occurred mostly from 04:00 - 10:00 h, being highest (63 %) from 07:00 - 08:00 h. Throughout the breeding season no striking changes in the activity patterns could be observed, except for lying and walking, which decreased and increased respectively. The found behavioural time budget largely coincided with findings of other studies on (feral) cat behaviour. Six out of the 10 behaviours e.g. sitting or lying showed a high classification (84-94 %), whereas some behaviours such as standing with head down or trot had a recall of 18-67 %, thus were considerably misclassified as other behaviours. The obtained knowledge of feral cat behaviour can be used further to complement other research. It may then contribute to a possible future assessment of the impact of feral cats on the breeding birds of Schiermonnikoog.

Keywords: feral cat behaviour, time budget, tri-axial acceleration, supervised classification

Introduction

The domestic cat (*Felis catus*) is one of the most successful and widespread alien mammalian predators throughout the world. Due to their large thermal tolerance, behavioural flexibility and extremely opportunistic predation behaviour domestic cats have revealed themselves to be capable of adapting to a wide range of environmental and climatic conditions (Courchamp, et al., 2003; Bradshaw, et al., 2012). Feral cats are domestic cats that reproduce in the wild and avoid both humans and domestic food sources (Berkeley, 1982) and are capable of surviving on most available prey species. Their diet includes a variety of native as well as introduced vertebrates such as land- and seabirds, mammals and to a lesser extent, reptiles (Fitzgerald, 1988; Courchamp, et al., 2003; Bonnaud, et al., 2011; Bradshaw, et al., 2012). Due to their broad diet and adaptability feral cats have been directly responsible for biodiversity loss (Atkinson, 2001; Courchamp, et al., 2003; Aguirre-Muñoz, et al., 2008) especially on islands. Medina et al. (2011) summarized the known global impact of invasive feral cats on insular biodiversity to have 'contributed to 33 (13.9 %) of the 238 modern bird, mammal and reptile extinctions' (p. 3505) and to the endangerment of '38 (8.2 %) of the 464 critically endangered birds, mammals and reptiles' (p. 3506). Based on the description of feral cat impacts on 120 different islands, 123 taxa of threatened birds (status 2008 IUCN Red List), of which 48 are endemic, have been affected globally (Medina, et al., 2011). Feral cats have strong negative effects through predation or even their mere presence (Hawkins, et al., 1999) that can lead to costly antipredator behaviour among their prey (risk effects) (Creel & Christianson, 2008) such as ground feeding (Fitzgerald, 1988) and ground nesting birds as well as on other species that are not adapted to evade or defend themselves and their young against alien mammalian predators (Bradshaw, et al., 2012). On small islands, this harmful impact is particularly experienced by birds that are not adapted to terrestrial predators (Courchamp, et al., 2003; Medina, et al., 2011).

Schiermonnikoog is a small island, which is located in the Dutch Wadden Sea. The island is part of three adjacent Natura 2000 areas ('Dunes Schiermonnikoog', 'Coastal zone of the North Sea', 'Wadden Sea') and represents an important area for birds to rest and breed (Ministerie van Economische Zaken, 2014[a]). It is home to 103 species of breeding birds, of which 25 are listed on the IUCN Red List of Threatened Species (Klemann & Kleefstra, 2012) and seven as Bird Directive Species (Ministerie van Econische Zaken, 2014[b]). The island is inhabited by a self-sustaining feral cat population of approximately 50 individuals (Op de Hoek, 2012). Based on scat analysis it was estimated that on Schiermonnikoog predation by feral cats causes the death of approximately 25 % (2738 birds) of the small breeding bird population annually and that they in all probability have an adverse impact on particularly small bird species, such as ground nesting birds e.g. sky lark (*Alauda arvensis*) and meadow pipit (*Anthus pratensis)* (Op de Hoek, 2012). However scat analysis might not reveal truthful records on the exact species or quantity of prey killed (Warner, 1985; Spotte, 2014). Only when comprehending behaviour, biology and ecology of feral cats effective management can be implemented (Fisher, et al., 2014; Spotte, 2014). Regarding a potential negative effect of feral cats on ground nesting birds it is particularly interesting to look at feral cat behaviour during the breeding season of these birds. Still little is known about behavioural time budgets of feral cats (Fisher, et al., 2014). This is mainly due to the fact that direct observations in the wild are challenging, since they often reside in remote and widespread areas (Fisher, et al., 2014) and display frightful or wary behaviour towards humans (Gosling, et al., 2013).

Over the past few years remote research and monitoring of behaviour by means of measuring the body posture and body movements has advanced due to devices such as accelerometers (Wilson, et al., 2008). When attached around the neck of a feral cat (Lascelles, et al., 2008; Watanabe, et al., 2005), a tri-axial accelerometer holding three transducers measures acceleration in three dimensions simultaneously (heave (y), sway (x), surge (z); Figure 1) (Grundy, et al., 2009; Laich, et al., 2008; Wilson, et al., 2008). Different behaviours generate different acceleration trace marks demonstrating three-dimensional movement realistically with which near continuous behavioural time budgets (Shephard, et al., 2008) of feral cats can be quantified. Therefore accelerometers are particularly suited to assess the behaviour of free-ranging undisturbed animals that are difficult to observe directly (Watanabe, et al., 2005).

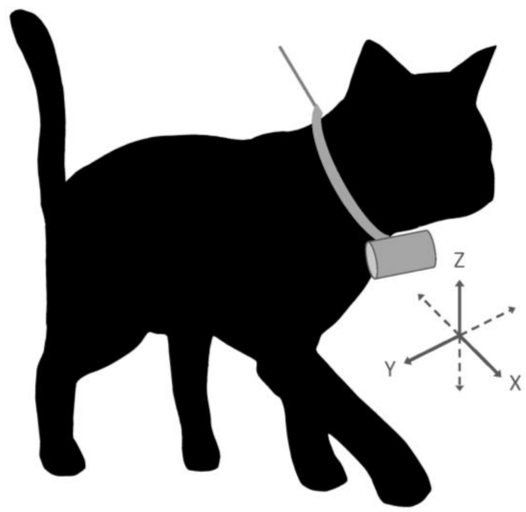

Figure 1 Feral cat wearing a collar equipped with a tri-axial accelerometer. The arrows represent the three dimensions heave (x), sway (y) and surge (z) recorded by the device. (Wilson, 2015)

In the present study acceleration data of nine feral cats, which were collared prior to the breeding season of ground nesting birds in 2014, were analysed. The objective of this study was to gain insight into the behaviour of feral cats on Schiermonnikoog including their circadian time budgets during the breeding season of ground nesting birds (May-July) to allow future quantification of hunting behaviour.

Methods

Study area

The island Schiermonnikoog is one of the five Dutch populated islands that are situated in the Wadden Sea (Wadden.nl, 2014). It is the smallest (≈200 km^2) of these islands (Wadden.nl, 2014) and is located about 7 km off the main land (53° 30'N 06° 10'E)

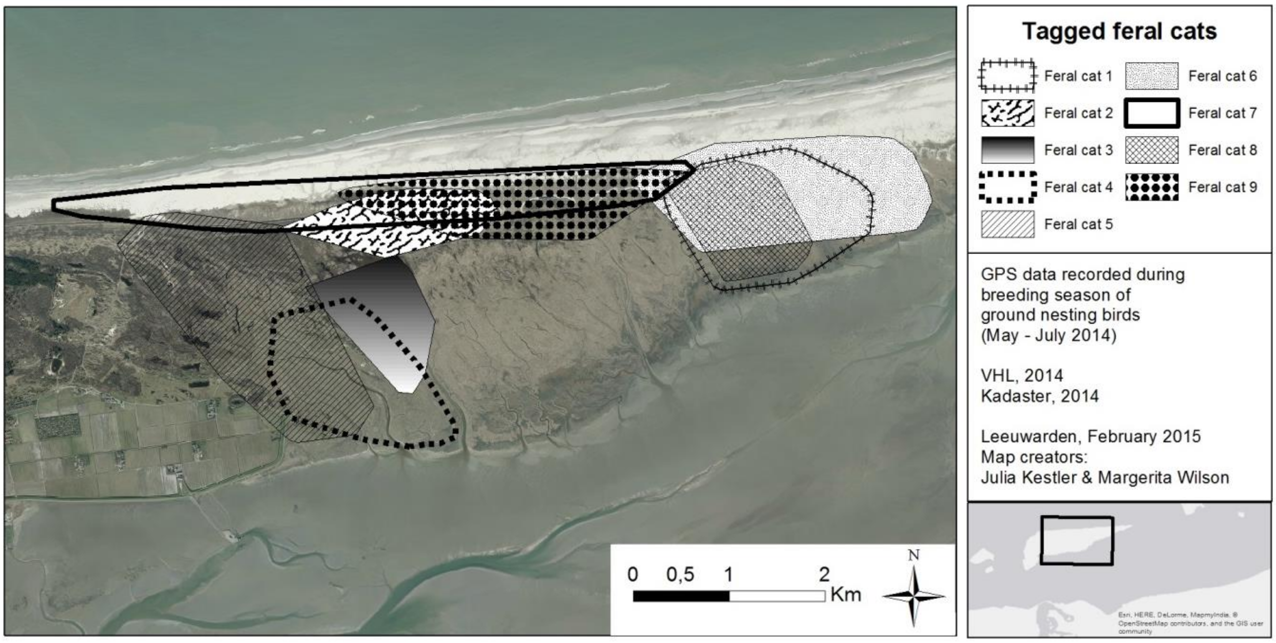

Figure 2 Home ranges of 9 feral cats obtained from the GPS fixes recorded from May to July 2014 on the middle and eastern part of Schiermonnikoog.

(DigitalGlobe, et al., 2014). The National Park Schiermonnikoog was established in 1989 (Ministerie van Economische Zaken, 2014[a]) and covers the major surface of the island (Wadden.nl, 2014). It comprises 5400 ha of dunes and salt marshes (Ministerie van Economische Zaken, 2014[a]) and represents an essential area regarding bird biodiversity (Nationaal Park Schiermonnikoog, 2011), especially during the breeding season of ground nesting birds. Breeding bird species like European Wheatear (*Oenanthe oenanthe*), Whinchat (*Saxicola rubetra*) and Short-eared Owl (*Asio flammeus*) are protected under Natura 2000, the European network of nature protection areas (Ministerie van Econische Zaken, 2014[b]) and are listed on the IUCN Red List of Threatened Species as 'least concern', however with a decreasing population trend (Birdlife International, 2012) as well as on the Dutch Red List as endangered or critically endangered (Vogelbescherming Nederland, 2014).

The various habitat types such as salt marshes, dunes, tidal flats and woods are important locations for more than 300 bird species that come to forage (Nationaal Park Schiermonnikoog, 2014), to rest and to breed (Ministerie van Economische Zaken, 2014a). Another fact that emphasizes the special character of Schiermonnikoog is the lack of other mammalian ground predators, such as fox, mink and weasel (Nationaal Park Schiermonnikoog, 2014) that would be potential competitors to the feral cat.

Study species

On Schiermonnikoog feral cats have established a self-sustaining population of approximately 50 individuals. The average population size consists of 31 (± 7.1) individual feral cats in the eastern part of the island, with a density of 2.6 feral cats per 100 ha, and of 19 (± 4.3) individual feral cats in the western part of the island, with a density of 6.8 feral cats per 100 ha (Op de Hoek, 2012). Based on the GPS data recorded during the bird-breeding season the mean home range of the feral cats was calculated to encompass 221 (± 93) ha (Figure 2), which is in accordance with Hoek (2012) and Recio & Seddon (2013), who estimated a minimum of 280 ha and a mean home range area of 273 (± 39.6) ha respectively. According to op de Hoek (2012) feral cats on Schiermonnikoog consume an approximate of 2.3 prey items per day. The diet includes voles (58.6 %), hares and rabbits (14.8 %) and birds (13.7 %) (Op de Hoek, et al., 2013).

Data sampling & collection

In April 2014 nine feral cats (> 2.3 kg) were captured using baited live traps (Katzenfalle 27904) (Drahtexpress, 2015) following the methodology of Lammertsma et al. (2011). The traps were set in areas with the highest chance of capture in the middle and eastern part of the island. Trapping and collaring of the feral cats was in accordance to the

Dutch Flora and Fauna act (FF/75A/2013/097) as well as the Animal Experiments Act and the Dutch Ethics Committee on animal experiments (DEC Groningen 6796A). After capture the feral cats were relocated to a 'squeeze cage' (Kombifalle 27906) (Drahtexpress, 2015), anesthetized, equipped with 115 g GPS-ACC-tags (e-obs digital telemetry 1C-light) (≤ 5 % of the body weight) and subsequently released at the trapping location. The tags included an Ultra High Frequency (UHF) pinger (868/916MHz bands) (e-obs GmbH, 2013a), a GPS (U-Blox LEA-4S), and a tri-axial-accelerometer (ACC) (e-obs GmbH, 2013b).

During the breeding season of ground nesting birds (calendar week (CW) 19-31) the tags of the feral cats were set to measure tri-axial acceleration 24 h a day at intervals of 180 s with a burst length of 8,85 s and at a sample rate of 56.23 Hz for three axes (18.74 Hz per axis). The GPS device measured the location of the tagged feral cat at an interval of 900 s and a burst length of 5 measurements per 1 s. Behavioural feral cat observations were conducted in October and November 2014 and subsequently linked to ACC measurements, which compiled the supervised classification training dataset. During these field observations three feral cats were tracked. The tags were set to measure ACC at intervals of 20 s with a burst length of 10,35 s. The remaining seven feral cats were not followed due to exhausted tag-batteries prior to the tracking period or an inaccessible area due to autumn flooding. At large distances feral cats were located via UHF-radio connection. At a short distance GPS fixes were used to visualize and find the exact location of the feral cat. The behaviour of the feral cat was recorded by one person from a distance of 5-50 m using a hand held video-camera (Sony HDR-CX280E) at 25 frames per second with a time leap of 0.040 s (video compression MPEG-4 AVC/H.264) and later synchronized with a hand held GPS.

In addition to the feral cats, a housecat was observed and video recorded wearing two different tags (e-obs digital telemetry 1C-light) on two different occasions in January and March 2014. This was conducted to test the tag and to enlarge the training dataset. The tag of the housecat was set to measure ACC continuously.

Data preparation

The downloaded raw ACC data was transformed into physical units of m/s^2 (Nathan, et al., 2012) with the following linear formula: $a_i=(n_i-n_{i,zerog})\cdot c_i\cdot g$, with a_i representing the converted acceleration data of one spatial axis (i=axes x,y,z), n_i=one digital sample of raw data (values between 0 and 4095), $n_{i,\ zerog}$=raw value for zero acceleration and gravitation (ADC output), c_i=slope and g= standard gravitational acceleration on the Earth's surface (9.08 m/s^2) (e-obs GmbH, 2013b).

Table 1 Differentiated behavioural modes of feral cats (FC4, FC5, FC9) and House cat (HC) as well as the number of measurements (seconds) per behaviour per observed cat

Behavioural mode	Description	# seconds				
		FC 4	FC 5	FC 9	HC	Total
Feed	Standing, Sitting or lying centred; head usually down	0	0	100	319	419
Gallop	Three-beat gait; fore and hind legs of opposite side move forward and land simultaneously, other two legs move forward and land after one another	4	0	10	1	15
Groom	Sitting or standing; licking stomach, chest, genitals, tail, left or right side	0	136	146	96	378
Lie	Stomach, front and hind legs on ground; body curled on either left or right side	0	0	1331	138	1469
Lie centred	Stomach, front and hind legs on ground; body position centred	0	12	17	62	91
Sit	Hind limbs and rear on ground	10	10	1532	135	1687
Stand; head down	All four feet on ground; head down, slightly under level of back, exploring or sniffing ground	0	0	62	36	98
Stand; head up	All four feet on ground; head up, slightly above level of back	9	0	559	98	666
Trot	Two-beat gait; two feet on ground, fore and hind leg of opposite side move forward simultaneously	0	0	17	0	17
Walk	Three feet on ground, fore and hind legs on same side move forward almost simultaneously	0	0	837	128	965
		23	158	4611	1013	5805

The constants of the formula ($n_{i,zerog}$ and·c_i·g) were determined through tag-specific calibration prior to tag deployment (e-obs GmbH, 2013b).

In order to avoid ‘contaminated’ ACC segments, which contain two or more behavioural classes and may limit the classification power of the model (Bom, et al., 2014), fixed time segments of 1 s representing one behavioural class were used. Thus successive ACC measurements were segmented with a window of 18 measurements, which is the equivalent of ≈1 s. Each second was synchronised with the collected video footage and annotated to a behaviour using a predefined ethogram (Table S1) in combination with the software programme Avidemux 2.6.8. Collectively 5805 s of useful video footage were obtained from the four tracked cats. In total 10 behaviours were determined, each representing a unique ACC trace mark (Figure S1). Feral cat FC9 represented the majority (4611 s) of the total seconds succeeded by the housecat HC (1013 s). Feral cat FC4 and FC5 represented the least amount of seconds (23 s and 158 s respectively) (Table 1). Behaviours that represented a very small sample size such as sneaking (6 s) and digging (7 s) as well as event-behaviours that lasted less than 1s for example pouncing and springing (max 0.65 s) were not included in the analysis.

The two behaviours ‘lie’ and ‘lie centred’ were treated as non-active behaviour. The remaining eight behaviours represented active behaviour. In order to obtain a rough indication of potential hunting behaviour the behaviours ‘walk’, ‘trot’, ‘gallop’, ‘sit’, ‘stand; head up’ and ‘stand; head down’ were defined as possible hunting behaviour, since hunting excursions entail sequences of walking, standing and sitting (Panaman, 1980). The behaviour ‘feed’ was determined as a definite hunting behaviour, whereas the behaviours ‘groom’, ‘lie’ and ‘lie centred’ represented non-hunting behaviour.

Data analysis

The training dataset, that encompassed all ACC measurements that were labelled with feral cat behaviour using the collected video footage, was applied to learn and assign feral cat behavioural classes to ACC segments of the dataset recorded in the bird-breeding season. This was conducted with the python-based web application AcceleRater. A total of 15 summary statistics were computed on the training dataset for each axis, namely mean, standard deviation, skewness, kurtosis, (Bom, et al., 2014; Martiskainen, et al., 2009; Nathan, et al., 2012) maximum value, minimum value, (Martiskainen, et al., 2009; Nathan, et al., 2012), average difference between two axes (mean-diff), standard deviation of the difference between two axes (std-diff), wave amplitude, line crossings, 25 % percentiles, 50 % percentiles, 75 % percentiles, DBA (=dynamic body acceleration) (Watanabe, et al., 2005) and overall dynamic body acceleration (OBDA), which is the sum of the dynamic part of all axes together (Bom, et al., 2014; Nathan, et al., 2012; Shamoun-Baranes, et al., 2012; Shephard, et al., 2008).

Table 2 Confusion matrix: detailed classification performance (recall) of behaviours based on Random Forest Classification Model including precision and accuracy of each behaviour

In \ Out	**Feed**	**Gallop**	**Groom**	**Lie**	**Lie centred**	**Sit**	**Stand; head down**	**Stand; head up**	**Trot**	**Walk**
Feed	88.54	0	2.14	0.71	0	0	0.23	0.23	0	8.11
Gallop	0	86.66	0	0	0	0	0	0	6.66	6.66
Groom	1.85	0	83.59	0.26	0	1.58	0.26	1.32	0	11.11
Lie	0.74	0	1.02	93.66	0	2.51	0.06	1.0	0	0.88
Lie centred	5.49	0	8.79	0	67.03	9.89	0	1.09	0	7.69
Sit	0.65	0	0.77	0.41	0.11	90.8	0.11	5.45	0	2.25
Stand; head down	28.57	0	4.08	4.08	0	4.08	18.36	24.48	0	16.32
Stand; head up	1.65	0	0.60	7.35	0	31.98	0.45	48.79	0	9.15
Trot	0	0	0	0	0	0	0	0	41.17	58.82
Walk	2.07	0.10	0.51	0.62	0	3.21	0.10	4.55	0.10	88.70
Precision	81.72	92.86	84.49	95.16	96.82	83.32	66.67	63.98	77.78	79.41
Accuracy	97.74	99.95	97.93	97.16	99.45	92.16	98.47	90.97	99.97	94.30

The summary statistics of which the mean was significantly different between the classes (α=0.05) were applied to all models available in AcceleRater (K-nearest neighbours, Linear SVM, RBF kernel SVM, Decision tree, Random Forest, Naïve bayes, LDA, QDA, ANN). The model performance was validated by 10-fold cross-validation (Hastie, et al., 2009; Nathan, et al., 2012; Shamoun-Baranes, et al., 2012; Resheff, et al., 2014). In comparison to the other models the Random Forest model, which is a collective classifier that classifies according to the majority vote of a set of constructed classification trees (Hastie, et al., 2009; Resheff, 2014), achieved the highest overall performance with an accuracy of 84 % (± 0.76). Therefore, the Random Forest model was applied to label the dataset collected in the bird-breeding season.

Results

During a 24 h cycle most active behaviour occurred during hour 20-22 (22:00-01:00 h) (‘feed’=4 %, ‘stand; head up’≈9 %, ‘walk’≈17 %, ‘sit’≈22). From hour 2-7 (04:00-10:00 h) feral cats spent the majority of the time lying with a distinct peak (63 %) during hour 5 (07:00-08:00) (Figure 3).

Throughout the bird-breeding season feral cats spent most of their time exhibiting non-active behaviours (‘lie’ ≈38 %, ‘lie centred’ ≈ 1 %). Active behaviours such as ‘sit’ (≈27%) ‘walk’ (≈11 %) were exhibited less frequent. On a weekly basis hunting behaviour (‘feed’) represented only a fraction of the entire week (≈3 %). Possible hunting behaviour (‘walk’, ‘sit’, ‘stand; head up) covered the second most percentage of the weekly activity (≈45 %), whereas the three behaviours ‘lie’, ‘groom’ and ‘lie

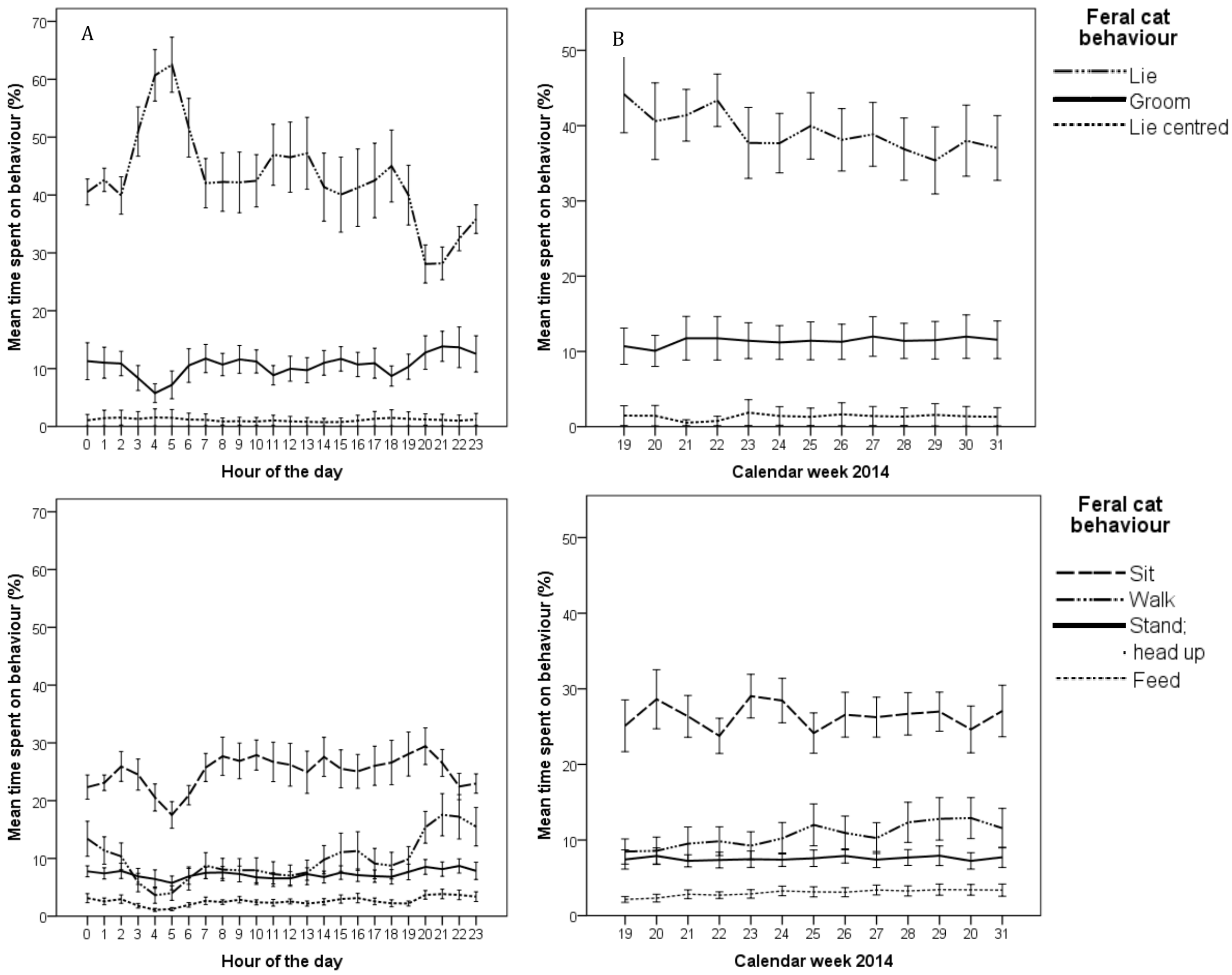

Figure 3 Mean percentage of time spent (± 1 SE) on feral cat (n=9) behaviour for each hour of the day based on GPS time (UTC time + 16 s) (to obtain local time 2 h must be added) (A) and for each week of the bird-breeding season (calendar week 19-31) (B) constructed from pooled tri-axial acceleration data. The behaviours ‘gallop’, ‘stand; head down’ and ‘trot’ were not visible in the graph (in total ≈1.5 %) and were therefore omitted in the legend.

centred', which represent non-hunting behaviours, embodied approximately half of the weekly time budget (≈51 %). Assuming that the amount of time spent on a behaviour in week 19 represents 100% a general decrease occurred in the amount of time 'lie' was exhibited accumulating up to a 36 % difference between CW 19 and CW 30. The behaviour 'walk' was displayed with an increase of 63% in CW 29/30 when comparing with the percentage of 'walk' in CW 19. Likewise 'feed' rose to 150 % in CW 21-31 in contrast to CW 19/20.

In the training data set the most frequently recorded behaviour was 'sit' (1687 s) followed closely by 'lie' (1469 s) and 'walk' (965 s) (Table 1). The behaviour 'lie' yielded the best classification with a recall of 94 %, succeeded by 'sit' with a recall of 91 % (Table 2). The behaviours 'feed' and 'walk' were also determined well with a recall of 89 %. 'Stand; head down' acquired the lowest recall (18 %). While 41 % of 'trot' was classified correctly, 58 % was misclassified as 'walk'. Also 'stand; head down' was misclassified as both 'feed' (29 %) and 'stand; head up' (25 %) while 'stand; head up' was mainly misclassified as 'sit' (32 %) (Table 2).

The relation between recall and the number of sampled cats presented R^2=0,143 and between recall and the amount of sampled seconds R^2=0,298 (Figure 4). 'Sit' was successfully classified with a sample size of 4 and 'trot' was classified rather inadequately (41 %) with a sample size of 1 (Figure 4 A). In contrast to this 'lie' achieved a high classification performance (94 %), although only two cats were observed exhibiting this behaviour and 'stand; head down' was considerably misclassified despite a larger sample size of 3. On the other hand, 'gallop' yielded a very high classification performance (87 %) even though very few seconds (15) of this behaviour were recorded on video, whereas 'stand; head up' was considerably misclassified (49 %), in spite of 666 sampled seconds (Figure 4 B).

The average accuracy (Table 2) was 97 %; 'trot' having the highest (100 %) and 'sit' the lowest (92 %). Concerning the relation between accuracy and the number of sampled cats (R^2=0,213) both low (90 %) and high (99 %) accuracies were achieved for behaviours 'stand; head up' and 'lie centred' respectively with n=3 (Figure S2). Also a high accuracy (100 %) was attained for 'trot' with n=1 and low accuracy (92 %) was achieved for 'sit' with n=4. The relation between accuracy and the amount of sampled seconds (R^2=0,484) showed two outliers 'stand; head up' and 'lie'. The precision varied between 79 % and 97 % for all behaviours with the exception of 'stand; head up' (64 %). The relation between precision and number of sampled cats achieved R^2=0,035 and between precision and amount of sampled seconds R^2=0,012 (Figure S3).

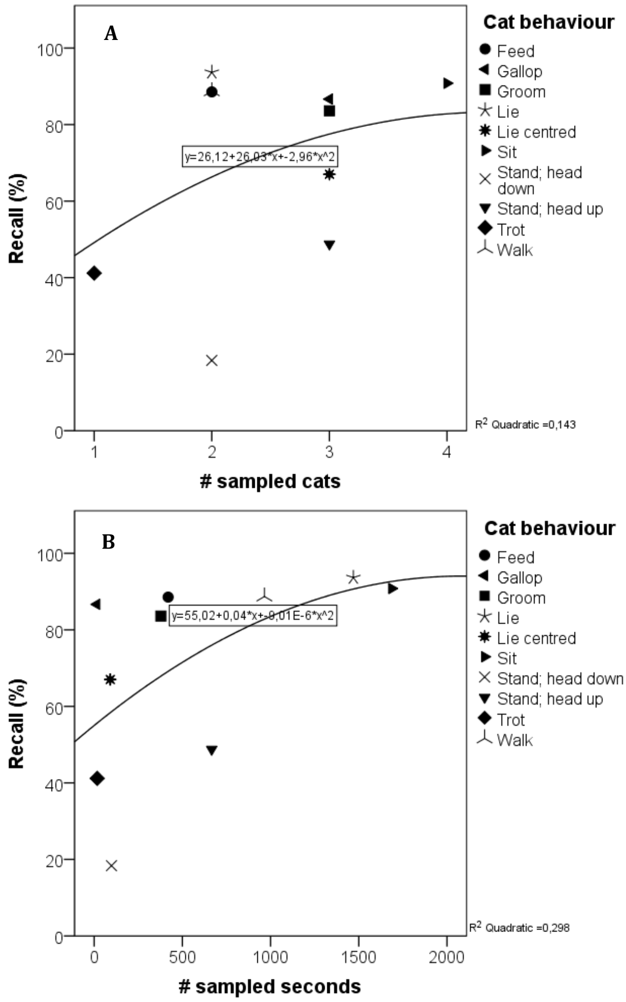

Figure 4 Relation for each behavioural class of the training dataset between recall and number of sampled seconds (A) and between recall and number of sampled cats (B).

Discussion

During the bird-breeding season the feral cats were most active around the time of sunset and up to four hours after sunset (earliest sunset: 21.00; latest sunset 22.08h) (sunrise-and-sunset.com, 2011-2015), which is especially visible in the increase of walking behaviour. The percentage of active behaviour during peak activity was approximately 70 %. These outcomes are similar to Page et al. (1992) who estimated a peak in feral cat activity (≈75 %) in an urban environment around the time of sunset and most sleeping and resting behaviour (≈55-65 %) to occur during 06.00-16.00 h with peaks at 07.00 h, 10.00 h and 14.00 h. Also Hilmer et al. (2010) found an increase in travelled distance by feral cats from 19.00-07.00 h, presenting a higher activity during night than at daytime. In contrast to this Panaman (1980) assessed most sleeping behaviour of female farm cats to be between dusk and dawn (82.1 %), as well as the majority of active behaviour to occur between dawn and dusk, thus depicting a rather diurnal activity, although this could be highly influenced by human care and a daily feeding regime (Hilmer, et al., 2010). According to Panaman (1980) farm cats exhibited sleeping (40 %), resting (22 %), hunting (15 %), grooming (15 %), travelling (3 %) and feeding (2 %) behaviours in a time period of 24 h. This behavioural time-budget concurs with the one found in the present study, which describes a mean of 44 % lying (compared to 'sleeping'), 11 % grooming, 25 % sitting (compared to 'resting'), and 3 % feeding. The amount of hunting behaviour found by Panaman can to some extent be compared to the behaviours 'walk' (10 %) and 'stand; head up' (7 %) determined in this study.

When contemplating the mean daily behavioural time-budget of feral cats, non-active behaviour accounted for 44 %, whereas 56 % comprise active behaviour. This coincides with the findings of Eckstein & Hart (2000) who investigated the behaviour of domestic cats and described non-active behaviour ('sleeping or resting') to represent 50 % of a 12 h time budget, as well as 46 % as general activity ('sitting or mobile'; without eating and grooming).

In general the mean percent of displayed behaviours on a weekly basis stayed constant throughout the bird-breeding season, with an exception of 'feed', 'lie' and 'walk'. This change in pattern of the behavioural cycle could be influenced by various factors such as interactions with other competing feral cats and food availability (Piccione, et al., 2013).

Regarding the approach of long-term recording and determining feral cat behaviour the use of accelerometers is highly suited (Laich, et al., 2008; Nathan, et al., 2012; Shephard, et al., 2008; Watanabe, et al., 2005). This study demonstrates the successful classification of feral cat behaviour using the new web-based application AcceleRater, which enables easy and rapid analysis of acceleration data (Resheff, et al., 2014). Still, impaired measurements of the three axes could have arisen, if the tags of the feral cats did not stay in a ventral position invariably. To avoid misclassification due to the turning of the tags, one could use the resultant of the three axes (SQRT(X-value^2+Y-value^2+Z-value^2)). The disadvantage however is, that the resultant does not generate distinguishable trace signals of the different behaviours as clearly as all three axes together. It is very difficult to correct the effect of a turned tag and further research on this subject is necessary. Also it was assumed that the successive ACC segments within one burst (thus within 8 s) were independent. However, this is not the case, since all the ACC segments of the same individual are actually dependent on each other. Yet, when analysing a subsample (only one segment per burst) the overall accuracy of the model decreased with only 4 %, suggesting that the dependency effect is marginal. It was anticipated, that a larger training dataset derived from several individuals could lessen the dependency effect.

One would expect that the accuracy decreases with a higher sample size, since the variation between different cats increases as well. However there is no clear relation between accuracy and sample size (R^2=0,213). In general the relation between accuracy and the amount of sampled seconds (R^2=0,484) showed that accuracy decreases when the amount of sampled seconds increases. The classification performance (recall) could neither be well explained by the number of sampled cats (R^2=0,143) nor the amount of sampled seconds (R^2=0,298). In total six out of the 10 classified behaviours showed a high classification performance. Bom et al. (2014) found in his study on crab plovers that some behaviours (e.g. attack and peck) were classified less correctly, since they either consisted of a small sample size, the acceleration measurements were difficult to distinguish or the time span of the behaviour was too short (event-behaviours). In this study 'trot' had a small amount of sampled seconds and was easily misclassified as 'walk', which can also be explained by its similar course of movement. Likewise the considerable misclassification of 'stand; head down' as 'feed', was not surprising since both behaviours are characterized by the same body posture (head bent down and standing on all four feet) (Table S1), the only difference being the movements of the head caused by chewing on or tearing prey. In comparison to this, behaviours such as 'sit' and 'lie', both characterized by a high number of sampled seconds, yielded a high classification performance (Figure 4 B). 'Gallop' on the other hand was also classified very well, despite a low number of sampled seconds, which is due to its ACC measurements' distinctiveness (Figure S1). In general 'walk' and 'groom' resulted in misclassifications of other behaviours, likewise it was described in the study of Watanabe et al. (2005), who classified seven different cat behaviours based on an accelerometer measuring only one axis. It might be advantageous to label behaviours as 'unknown', if these lie under a specific threshold (Nathan, et al., 2012). However, at present this is not possible in the web-based application AcceleRater. Also it is not clear which of the 15 applied summary statistics were significant (α=0.05) and thus eventually used in the model Random Forest.

In a study with domestic farm cats Turner & Meister (1988) estimated that the duration of a hunting excursion consists of about 30 minutes and the investigation of a potential prey site of 3 minutes. Since hunting behaviour of cats entails particular sequences, such as galloping, followed by seeking or ambushing (Panaman, 1980), Watanabe et al. (2005) assumed that hunting behaviour of cats in the wild can easily be distinguished due to the specific pattern in the ACC measurements. Typical hunting sequences that were observed in the field consisted of periods of walking, standing and sneaking, followed by a pounce to catch prey. A sucessful pounce was succeeded by a period of handling or struggling with prey. Although the event-behaviour 'pounce', which is a significant part of hunting behaviour, was observed in the field as well as differentiated from other behaviours, it was omitted from the training dataset, since sample size was considerably reduced due to its short sequences (<100% of 1 s). Bom et al. (2014) therefore suggests that it can be beneficial to use variable- instead of fixed-time segmentation. Moreover the ACC measurement frequency did not allow to identify successive behavioural patterns, since only 8 seconds were recorded every 3 minutes. In order to be able to detect sequences of hunting behaviour, continuous ACC recordings are thus required, which would result in enormous datasets, if measuring over a long period of time (e.g. 3 months).

Concluding, a substantial amount of behaviours could be labelled with a high clasification performance, providing an insight into the behavioural time budget of feral cats during the bird-breeding season on Schiermonnikoog. Although hunting behaviour could not specifically be determined, the results suggest that it might be possible when changing the ACC recording to continous sampling and subsequently analysing the data with regard to sequences. Then, by linking detailed information about feral cat behaviour to data on breeding birds, e.g. the amount of time feral cats exhibit hunting behaviour in close proximity to bird territories, one can test the potential relation between locations of feral cats and the birds' nesting sites. Then it would be possible to evaluate the possible effect the feral cats have on the ground-nesting birds.

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Supplementary Material

‘Acceleration derived feral cat (*Felis catus*) behaviour during ground nesting bird-breeding season on the island of Schiermonnikoog’

Julia Kestler & Margerita Wilson

This supplementary material consists of tables, methods and figures used in the paper.

Methods

Data sampling & collection

Regarding the behavioural field observations in October and November 2014, the tags were set to measure acceleration with a byte count of 873, which equals a burst length of about 10,35 s. Ideally the tag would have recorded ACC continuously. However this meant that when the cat was lost out of sight, it could not be tracked back with the UHF transmitter, which would have resulted in loosing valuable data. The GPS timeout was set at 120 s, which means that the device searched for a maximum of 120 s to receive a GPS signal In order to save battery, the ACC recordings were turned off after each observation and the GPS settings were set to record a GPS fix every 7200 s.

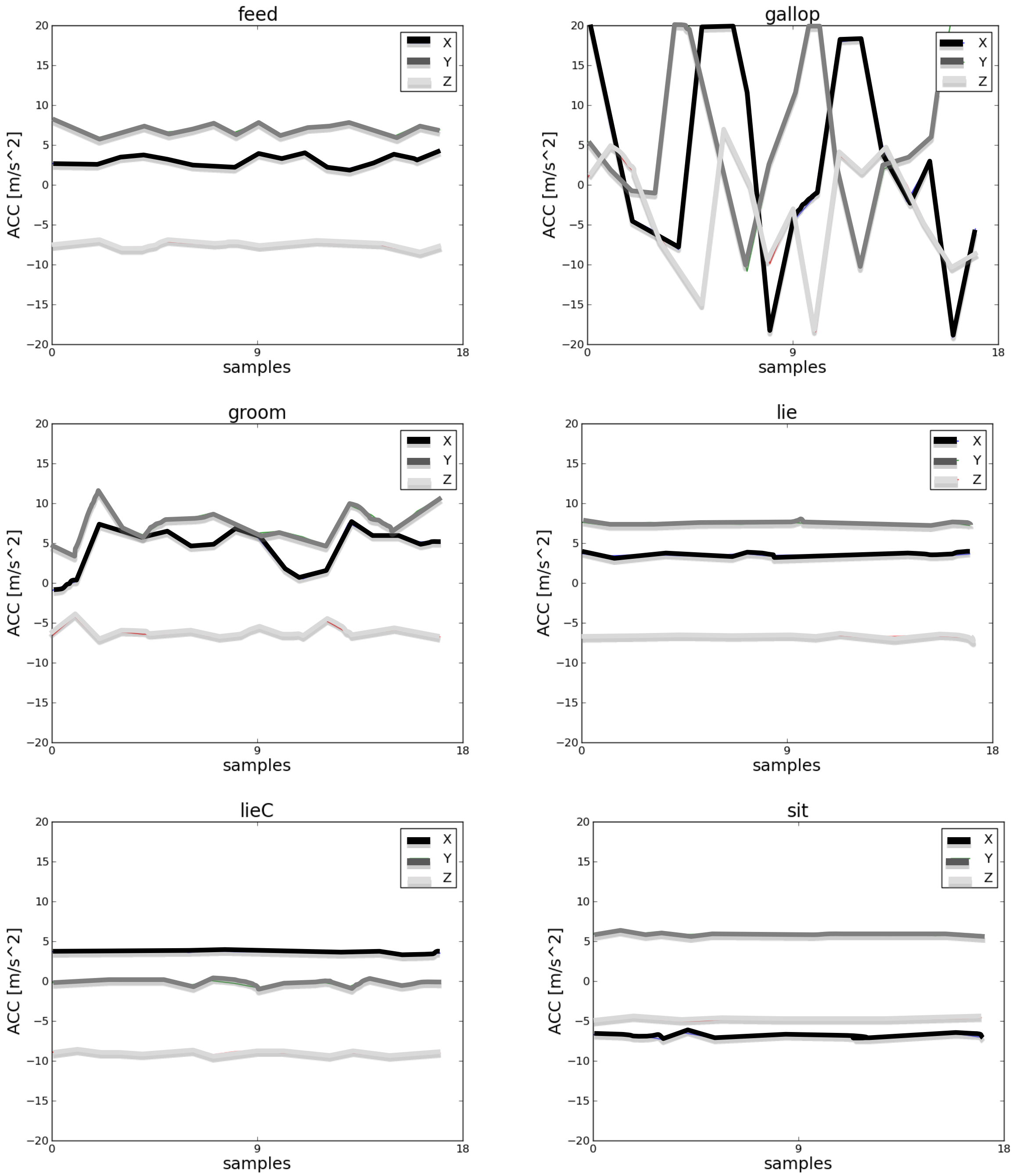
Tracking occurred while the pinger, emitting a tag-specific UHF-signal, was active (between 8.30 am - 18.00 pm). One feral cat was tracked at a time. However, another feral cat within reaching distance was tracked and observed, if after one hour of tracking no signal was received or a signal was received, but the duration until actual visualisation exceeded three hours. Also, a different feral cat was tracked and observed if after a successful observation period the feral cat reached out of sight and could not be relocated within one hour. Once the approximate location of a feral cat was known, the settings of the tag were adjusted remotely using a handheld device (BaseStation II, e-obs digital telemetry, Germany), which was connected with a laptop via Hyper Terminal (version 6.1). The GPS setting was set to record a GPS fix at an interval of 300 s and a burst length of 1 s. After 15 min the data was downloaded and the GPS fixes were visualized in Google Earth. A GPS device was used to find the exact location of the feral cat.

In order to be able to synchronize the time of the video footage with the ACC data, a GPS device showing the GPS time was recorded at the end of each video recording. If only the direction of the location of the feral cat was known, the person holding the video-camera walked in the given direction until the feral cat came into sight. In order to prevent disturbance feral cat behaviour was recorded as long as the feral cat was visible, preferably at a larger distance. The person handling the video-camera recorded the feral cat's behaviour from a distance of approximately 2 m to 50 m. ACC data was downloaded onto the BaseStation II at the end of the observation session.

Data preparation & analysis

The GPS and raw ACC data of the tags were downloaded onto a computer using the e-obs digital telemetry DataDecoder Software (version 5.1.6). Subsequently the video recorded cat behaviour was linked to the time of the corresponding ACC measurements. Eleven behavioural classes were defined that were initially divided into 21 behavioural modes describing the body posture or behavioural class in more detail (Appendix I). However some behavioural modes such as sneaking (6s) and digging (7s) were observed too little and were thus omitted for further analysis due to the low amount of sampled seconds. Other behavioural modes as for example the different types of grooming and lying on left side or on right side were reclassified into one general behavioural class or omitted completely (digging), since no significant distinction between the different behavioural modes could be established. The classification performance was assessed through calculating the overall accuracy as well as the accuracy, precision and recall for each behavioural class.

- Recall: for example 94% of the ACC segments to which the behaviour 'lie' was assigned in the test-set will be correctly classified as this behaviour.
- Accuracy: the likelihood that a sample of ACC measurements in the test-set will be assigned correctly to the particular behaviour or to another behaviour.
- Precision: the likelihood, that an assigned behaviour in the test-set really matches this particular behaviour.


feed
gallop
groom
lie
lieC
sit
X
Y
Z
ACC [m/s^2]
samples
20
15
10
5
0
−5
−10
−15
−20
0
9
18

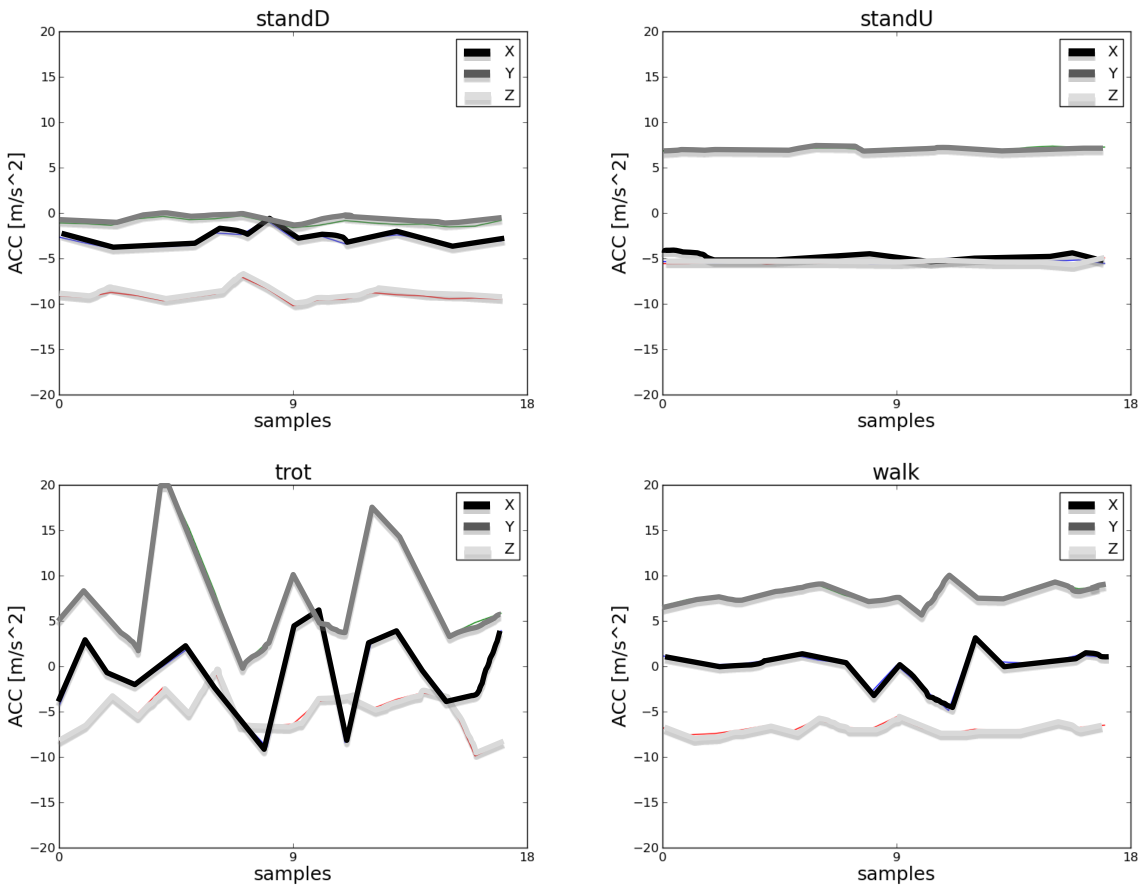


Figure S1 Visualized feral cat behaviour based on tri-axial acceleration data (‘LieC’ = ‘Lie centred’, ‘standD’ = ‘stand; head down’; ‘standU’ = ‘stand; head up’).

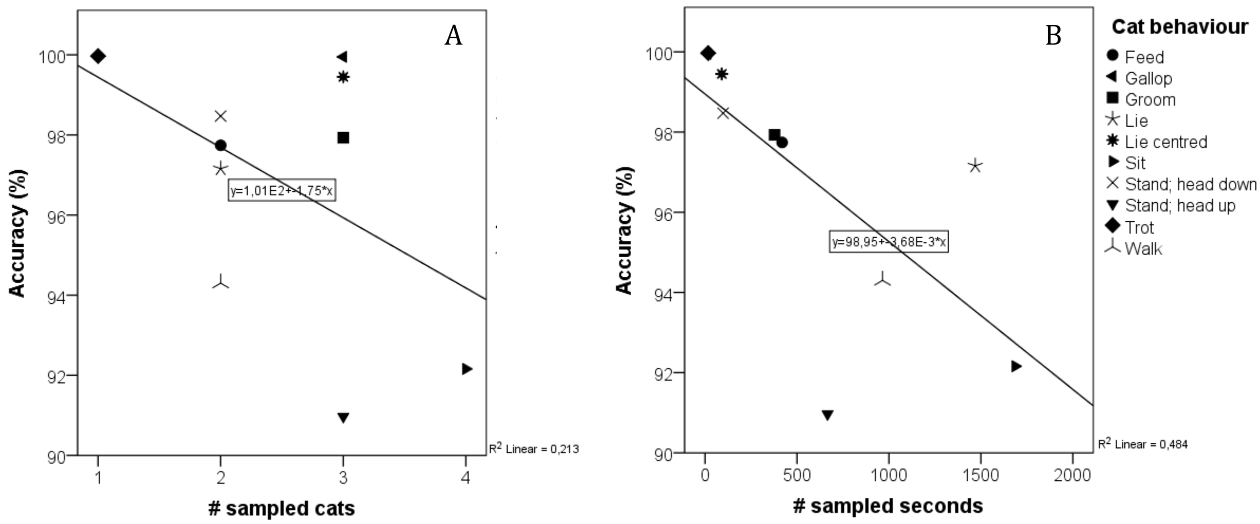


Figure S2 Relation for each behavioural class of the training dataset between accuracy and number of sampled cats (A) as well as accuracy and amount of sampled seconds (B). The accuracy for 'gallop' overlaps with the accuracy of 'trot' (B).

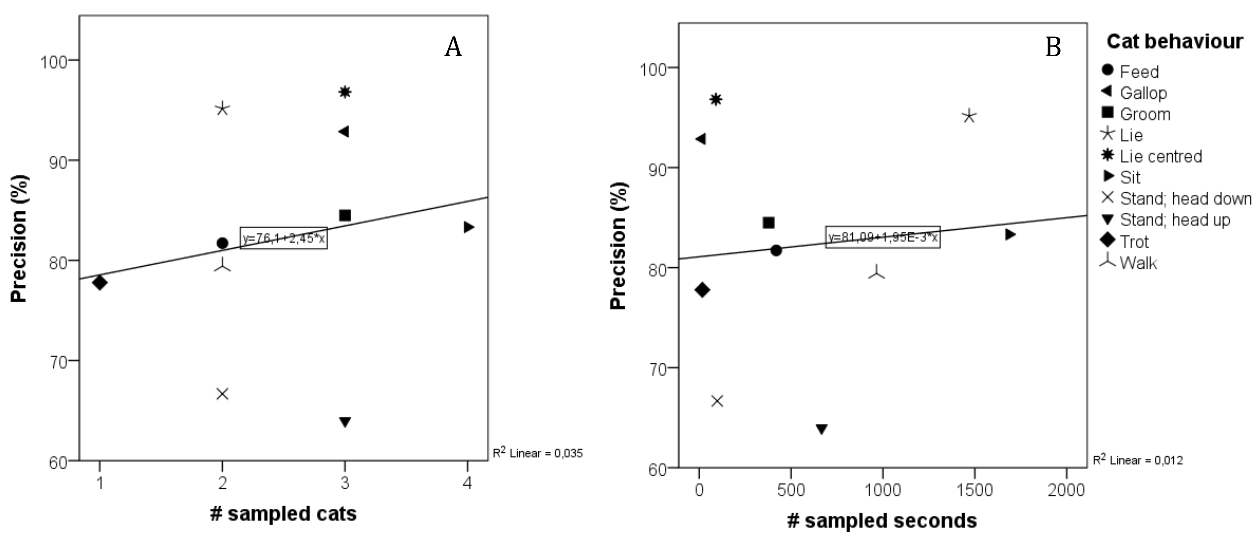


Figure S3 Relation for each behavioural class of the training dataset between precision and number of sampled cats (A) as well as precision and amount of sampled seconds (B).

Table S1 Ethogram of behaviour classes and behavioural modes as well as the respective codes used for analysis. Behavioural classes that are shaded grey were omitted from the analysis since they were either not observed in the field or resemble an event-behaviour, which lasts less than 1s.

Behavioural class	**Behavioural mode**		**Behavioural mode code**
Travel (from one location to another)	Walk	three feet on ground, fore and hind legs on same side moving almost simultaneously	101
	Trot	two-beat gait; two feet on ground, fore and hind leg of opposite side move forward simultaneously	102
	Gallop	three-beat gait; fore and hind leg of opposite side move forward and land simultaneously, other two legs move forward and land after one another	103
Sneak (moving slowly forward in a crouched position)		fore and hind limbs are flexed, stomach close to ground, one leg moves forward at a time	200
Jump (moving quickly forward)	Pounce	attempt to catch a prey; fore feet leave ground, hind feet push body in air also leaving the ground, all feet in air for a brief moment, landing first on fore then on hind feet	301
	Spring	bypassing obstacles (vegetation e.g. high grass or bush); fore feet leave ground, hind feet push body in air also leaving the ground, all feet in air for a brief moment, landing first on fore then on hind feet	302
Stand (on all four feet)	Stand; head down	all four feet on ground; head down, slightly under level of back, exploring or sniffing ground	401
	Stand; head up	all four feet on ground; head up, slightly above level of back	402
Sit (hind limbs and rear on ground)		Head position: up	501
Lie (with front and hind limbs and stomach on ground)	Lie centred	centred	601
	Lie	curled to right side curled to left side	600
Groom (while sitting or standing)	Grooming with/of:	tongue (licking)/ fore legs tongue (licking)/ hind legs tongue (licking)/ stomach-chest-genitals-tail tongue (licking)/ left side tongue (licking)/ right side fore paw/ head (face/ears) hind paw/ head (face/ears) shaking head and/or body	700
Feed (while standing, sitting or lying/centred)		head down	902
Drink (while standing or sitting)			950
Dig (moving ground material, mostly with one forepaw)			980
Handle (handling prey/struggling with prey/catching prey)			990