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Performance of the real-time bat detection system DTBat at the wind turbine of Calandawind, Switzerland

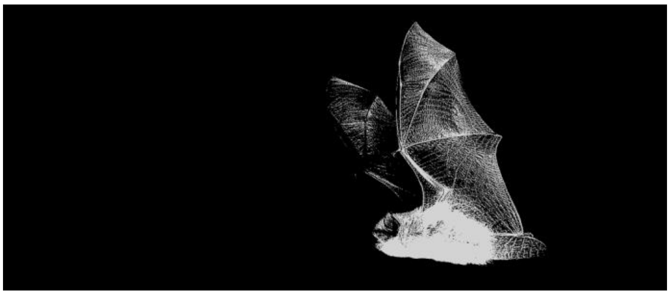

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Table of contents

1. Introduction

Collisions with moving rotor blades of wind turbines (WT) are often deadly to bats and birds. An increase of cut-in wind speed and preventative shutdown periods of WT are suggested measures to minimize the collision rate. Wind park operators are under high pressure to produce energy in a highly competitive market of renewable energy, therefore efficiency in power production is crucial and operators are highly interested to optimize shutdown periods. DTBat is a newly developed module in the DTBird system (www.dtbird.com), which was at the time of the study not yet fully commercial. DTBat is described as “a self-working system developed to reduce bat mortality in wind farms, that detects bat calls in real time, and takes automatic actions linked to bat activity detected, as the Stop of a Wind Turbine Generator”. DTBat is composed by an Analysis Unit which controls the Bat Detection Module and the Stop Control Module. The Analysis Unit contains a Bat Filter Software which should identify bat calls automatically and in real-time.
In this project the DTBird and DTBat systems were installed and tested on a Vestas V112 machine at the WT Oldis of Calandawind in Haldenstein, canton GR, Switzerland.

2. Aims of the study

The main aim of this part of the study with bats was to evaluate the performance of the DTBat system to detect bats in real-time and to control the wind turbine by a stop program to reduce collision risk. For this purpose:

- Bat detection of the DTBat system at different altitudes of the WT was compared to the bats recorded by SWILD at the nacelle of the WT.
- The effectiveness of a Fixed Environmental Stop Program, developed by SWILD, based on simple environmental parameters and part of the operating approval for Calandawind, was investigated by monitoring bat activity and the occurrence of different bat species.
- The data collected for the Fixed Environmental Stop Program was used as reference to compare the performance of the control program by DTBat. The most promising scenarios of the DTBat stop programs were evaluated in relation to efficiency of bat detection and to the loss in energy production.

3. Methods

3.1 Data collection SWILD

SWILD recorded bats in the frame of the regular bat monitoring program „Erfolgskontrolle Fledermäuse“ at the WT Oldis of Calandawind from 15 March 2014 to 31 October 2014. The recording unit was installed in the nacelle (119m, floor of rear side). The equipment is proven and used for years for long term monitoring of bats in the nacelle (e.g. Brinkmann et al. 2006).

Recording units: Acoustic permanent detection with broadband ultrasound detection units (Batcorder 2.0, Ecoobs, Nürnberg, Fig.1): Ultrasound signals are detected in real time with a sampling rate of 500 kHz. All recorded sound data is stored on a data logger with a digital time stamp. To ensure data quality the performance of the recording unit and the sensitivity of the microphone is remotely monitored by daily status by SMS (Short Message Service).

***Fig. 1**: Batcorder 2.0 with GSM remote control unit*

Control periods: Regular controls at intervals of 2 and 6 weeks, additional controls after radio alarm was received. At every control the recording unit was tested on-site, data was transferred and stored and the sensitivity of the microphone was tested.

Microphone sensitivity: Microphone sensitivity was either tested with the broadband ultrasound generator AutoBat (Sussex, UK) or with the in-build ultrasound generator. In case of reduced sensitivity the microphone was replaced immediately. Batcorder sensitivity was adjusted to maximum (-36db).

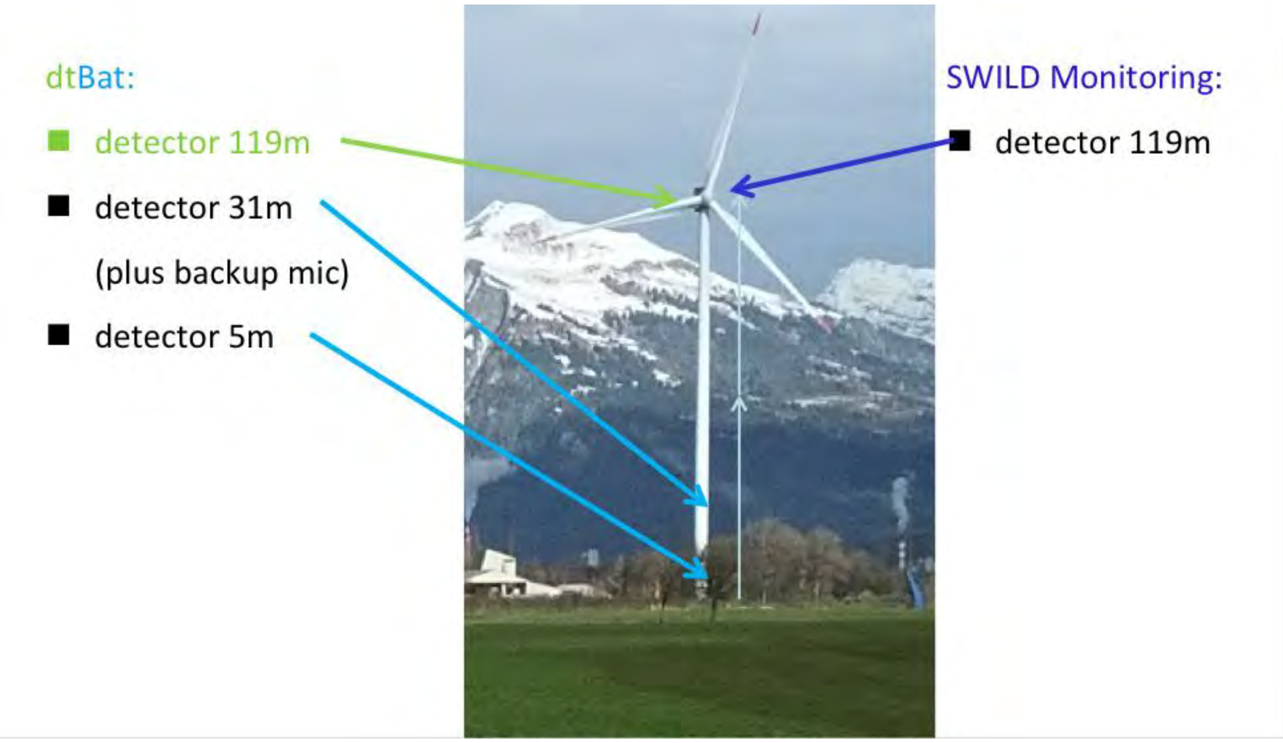

Fig. 2: *Position of the recording units at the WT in Haldenstein. Recording units of DTBat at 119m in the nacelle, and on tower at 31m and at 5m. SWILD recording unit at 119m in the nacelle.*

Acoustic analysis: The sound files recorded were analysed according to a standardised, scientific reliable procedure developed by SWILD. The analyses are done in a multi-step method to guarantee well documented and comparable standardised data (SWILD, Bioakustischer Analysestandard, Herbst 2013).

Evaluation in multiple steps

1. Semi-automatic species identification afterwards in the lab by using the software bcAdmin and batIdent (bcAdmin 2.21, batIdent 1.03)
2. Species identification according to criteria developed by Hammer & Zahn („Bayrische Richtlinien“, 2009)
3. Random samples out of all species groups are validated manually by using the spectrogram and sound analysis software RAVEN pro 1.4. All bat passes of critical or rare species are always verified manually.

3.2 Data collection DTBat

DTBat detected ultrasound bat passes in three different heights:

- 119m above ground at the nacelle (floor of rear side, 1 recording unit next to the SWILD unit).
- 31m above ground (tower surface, 2 microphones at one recording unit)
- 5m above ground (tower surface, 1 recording unit)

For further details see the project report on the DTBat system (DTBat, 2015).

The ultrasound data recorded was processed by the Bat Filter Software and the data was uploaded and stored in an online Data Analysis Platform.
The entire data set was provided to SWILD for further analyses. The system was operational from the 1st July to the 31st October 2014.

Recording unit: Acoustic permanent detection with Anabat SD2 (Fig. 3)

***Fig. 3**: DTBat, Anabat SD2*

3.3 Parameters and Settings

Correcting for time shift using different bat detector systems

Because of different recording systems, microphone sensitivity and bat detectors used, it was necessary to estimate the time shift at which the different systems recorded bat activity in order to compare the data. The DTBat system used internet time over DSL connection. The SWILD units were set manually and the data therefore was corrected by adding a time delay. We found that the time shift was constant over time and that the Batcorder system of SWILD recorded bats with a mean **time delay d** = 15s (SD 40s) later than DTBat Anabat System.

Time to Stop: from bat activity trigger to complete stop of rotor blades

DTBat processor time between first trigger of recorded bat activity and stop signal to the wind turbine is about 7s. It is unclear how long it takes until the rotor blades are completely stopped or at least they are at a speed level at which we can exclude any harmful collisions of bats with the blades. According to Calandawind AG it takes about 7s, according to our own measurements at 6m/s wind speed about 30s and according to DTBat calculations 45s until the blades stop or the speed is very slow. Furthermore we can expect that the the **Time to Stop** varies depending on the type of WT and the wind speed. We took this variation into account by using five different time delays (from bat trigger to full stop) for our calculations:

- Initial model: Time to Stop = 0s (theoretical best case)
- Processor time only: Time to Stop =7s
- Processor time & blades completely stop 7s: Time to Stop = 7 + 7 = 14s
- Processor time & blades completely stop 30s: Time to Stop = 7 + 30 = 37s
- Processor time & blades completely stop 45s: Time to Stop = 7 + 45 = 52s

Stop Program triggered by first or second Bat Pass

Initially, we tested the multiple thresholds of bat activity which triggered the DTBat Stop program (1-3 Bat Passes / Time). However, because more than one Bat Pass (per time) resulted always in a reduced performance of mitigating the number of bats exposed, we finally present here only the best results when **1 Bat Pass (pass1)** was used for triggering the stop.

3.4 Comparison of bat recordings DTBat vs. SWILD:

Identified bat passes (called Bat Pass in DTbat reports) from DTBat and SWILD were systematically compared. Data completeness was monitored by comparing certain time intervals. Efficiency of bat protection and loss in energy production under different stop programs (several DTBat Stop Programs vs. Fixed Environmental Stop Program developed by SWILD) was estimated to evaluate the performance of the various bat protection regimes.

The following time periods were used for the analysis:

Full season:	Standardised recording from SWILD: 15.3. – 31.10.2014, with some outages because of technical issues from 21.-27.03, 19.7-6.8 and 7.10-22.10. Total period of 230 nights, N=196 nights of operation.
Study period:	Simultaneous recording period of DTBat & SWILD: 1.7 – 31.10.2014 (123 nights) for comparisons of bat activity and recording systems. Wind turbine was out of service during this period for 6 nights. Total N=117 nights of operation.
Assessment period:	Period with access to wind data used for estimations of mitigation performance and energy production losses (11.8 – 31.10.2014). Total 81 nights, outage 6nights, N=75 nights of operation.

4. Results of bat monitoring SWILD in 2014

4.1 Extent of monitoring data

The standardized bat monitoring for Calandawind was operational from 15 March to 31 October 2014, data were successfully collected from 196 nights (Fig. 4). Subsequently we call this period the "full season". In this "full season" **1479** bat passes were recorded (*Appendix Table A1*).
In the "study period", spanning from 1st July to 31 October, **1176** bat passes were recorded.

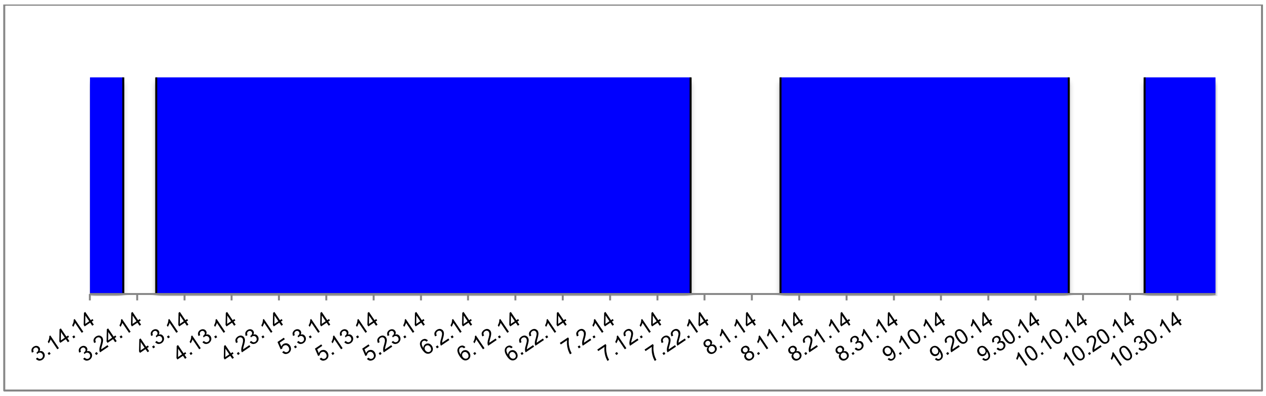

Fig. 4*: Extent of bat monitoring data recorded by SWILD (blue: full data; white: missing data).*

4.2 Bat activity and species richness

Overall 14 species groups were determined. These species groups contain at least **seven bat species** (see *Appendix, Table A2*).

The bat activity in the season of 2014 is presented in Fig. 5.
The average bat activity was relatively low in 2014 with 6.4 bat passes/night (a series of bat calls recorded when a bat is in the detection range of the microphone) compared to 25.9 bat passes/night in 2010 and 23 bat passes/night in 2013 (see *Appendix, Fig. A1*). Only around 1/3 of bat passes were recorded in 2014 compared to seasons 2010 and 2013 (*Appendix Table A1*). Highest bat activity with mean 19.5 bat passes per night were recorded during autumn migratory season in September (*Table 1*)

Table 1: *Mean bat passes (BP/night) and month recorded by SWILD detector during the "full season" (definition of time period see on page 9)*

	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct
mean BP/night	1.5	1.4	1.3	6.0	7.3	7.8	19.5	4.0

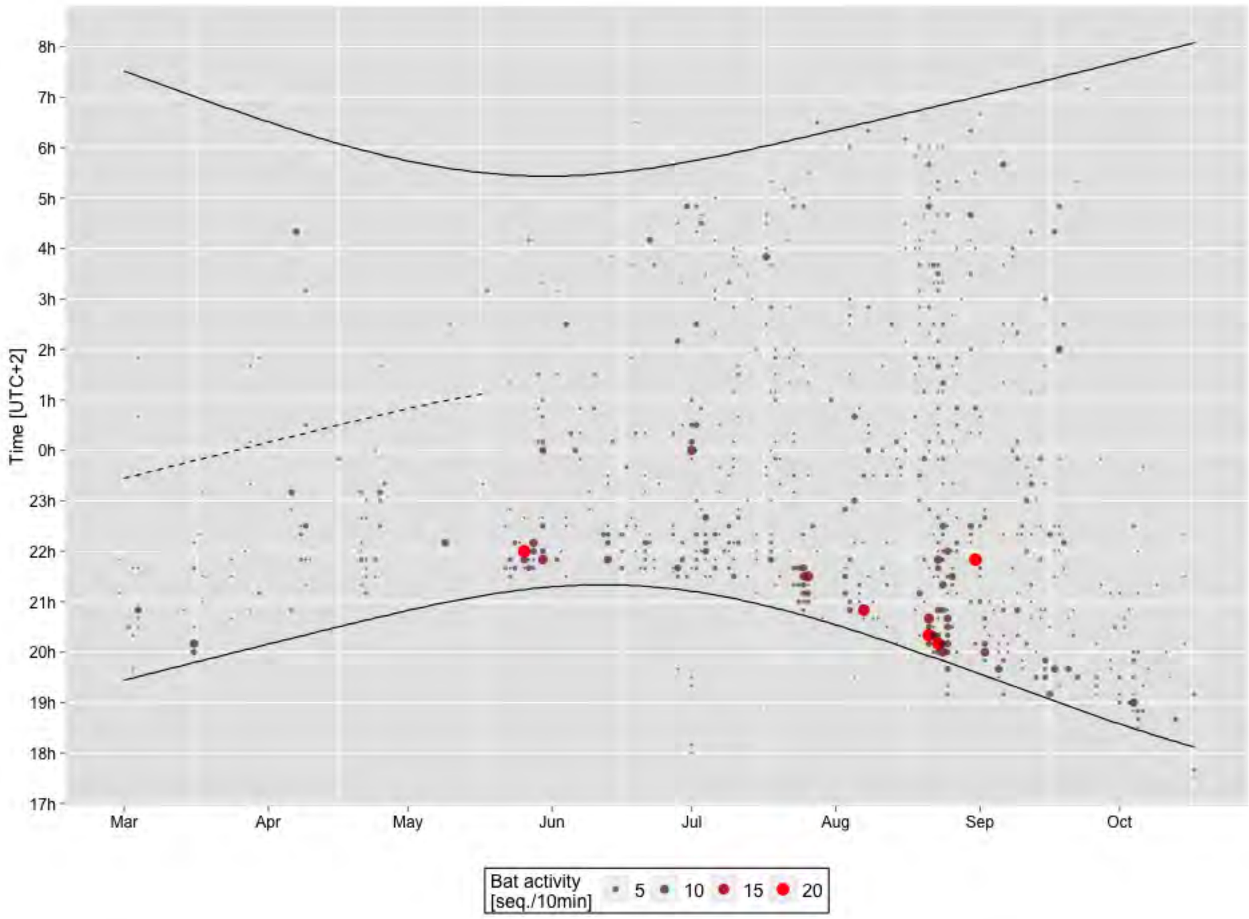

Fig. 5: *Bat activity at nacelle 119m, WT Oldis, Haldenstein in 2014.*

In the "study period" **76.9% of all bat passes belong to red listed species** (category: *NT near threatened - CR critical endangered;* Bohnenstengel et al. 2014). 30 Bat passes (2%) were determined as Particoloured Bats *Vespertilio murinus*, which are categorised vulnerable *VU* according to the Red List Criteria. Several bat passes of *Myotis* subspecies were recorded, which regionally have a high priority for protection (*Appendix Table A2*). We registered four species groups (NycVes, Nycmi, Nyctaloid & group Nathusius'-Kuhl's-, & Savi's Pipistrelle) and one species (Savi's Pipistrelle *Hyposugo savii)* with priority of protection in the Canton of Grison.

More than ½ of all bat passes belong to the species group *Nyctaloid* (69.6%), which includes Noctule, Lesser Noctule, Serotine, Particoloured Bat and Northern Bats. Pipistrelloid species represented 29.4% of all bat passes. As expected at nacelle height only few *Myotis* bat passes (0.3%) were detected. In total **80.5% of all bat passes were attributed to migrating species** (*Appendix Table A2*).

Most of the bat activity (833 bat passes of 1479 bat passes, 55.6%) were recorded during migration season in autumn between 15 August and End of October (*Fig. 5*). As a consequence the highest bat activity is contained in the "assessment period" (see definition on page 9).

5. Comparison of detectors used by DTBat & SWILD

5.1 Bat activity

Number of bats recorded are given in Table 2.

Table 2: *Bat activity recorded by DTBat & SWILD detectors during the comparable "assessment period" (definition of time period see on page 9).*

detector	bat activity			
	wind speed < 3m/s		*wind speed ≥ 3m/s*	*total*
	#	%		
DTBat [119 m]	356	67.42%	172	528
DTBat [30 m]	1587	58.37%	1132	2719
DTBat [30m + 119m]	1943	59.84%	1304	3247
SWILD [119m]	421	60.75%	272	693

The higher the measurement position the fewer bats were active. This indicates a reduced risk of bats exposed to the blades at wind turbines with large towers – if this is a general pattern.

5.2 Differences in bat detectors used by DTBat & SWILD

Detection range:	SWILD Batcorder detection unit was at nacelle only and pointed downwards. DTBat was equipped with three Anabat SDII bat detectors, each one installed at different heights. The detectors at 5m and 31m height were pointing down with a reflector below to detect the bat activity above. The bat detector at nacelle 119m was pointing down. It is known that the Anabat microphones have a very central biased detection range in comparison to the Batcorder which have a detection range relatively equal over 180 degrees.
Time stamp	Batcorder: time stamp at the end of each bat sequence. Mean time length of sequence during assessment period 1.74s ± 1.5 (mean ± SD)
Detection unit time	Batcorder: manually adjusted at each control on site (we found an average time lag of 15s after the DTBat recordings, including the duration of the recordings). Anabat: Adjustment through time server over internet (should be precise)

Because of technical differences in the two bat detector systems used in this study, we expected some deviations in the detection capacity of the two systems.
When we compare the recordings at 119m at wind speeds < 3 m/s, DTBat recorded 85% of the bat passes of SWILD, when the wind speed was above 3 m/s this relation was only 63%. This is most probably a consequence of the different microphone sensitivity and species composition.

We compared the number of bats recorded by the four bat detectors (3 x DTBat and 1x SWILD) to check for obvious irregularities or for seasonal trends (which might indicate problems in microphone sensitivity).

5.3 Completeness of data; DTBat vs SWILD monitoring

As expected bat activity was higher at the detectors lower to the ground (*Table 2, Fig. 6).*
In the "study period" the DTBat system recorded at 5m height 11'512 bat passes (70% of a total 16'500), at 31m height 4'063 bat passes (25%) and 913 bat passes (5%) at 119m in the nacelle.
In the same time period the SWILD detector recorded 1176 bat passes at 119m in the nacelle.

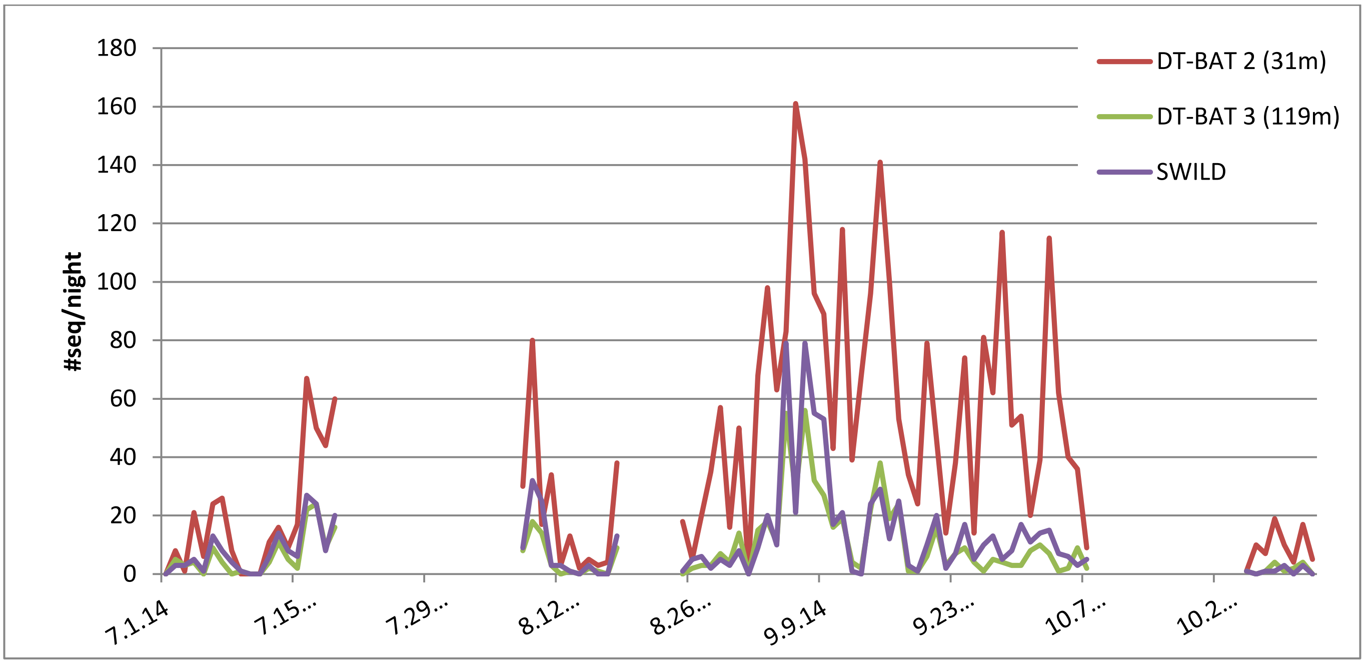

***Fig. 6**: Comparison of the number of bat bat passes recorded per night by the four bat detectors at various heights. DTBat at 31m at the tower and at 119m in the nacelle; SWILD at 119m in the nacelle.*

High activity on the ground indicates mostly foraging activity. This is especially expected near to the riverine habitat at 5m. This activity close to the ground should not be in conflict with WT, because it is far enough from the rotor swept area. Therefore we did not further consider the data from ground level.

In 79 nights DTBat detected 78% of all bat passes compared to SWILD recording at nacelle (119m). Therefore DTBat system was less sensitive compared to SWILD system, but showed good results for real-time detection (Fig. *7*).

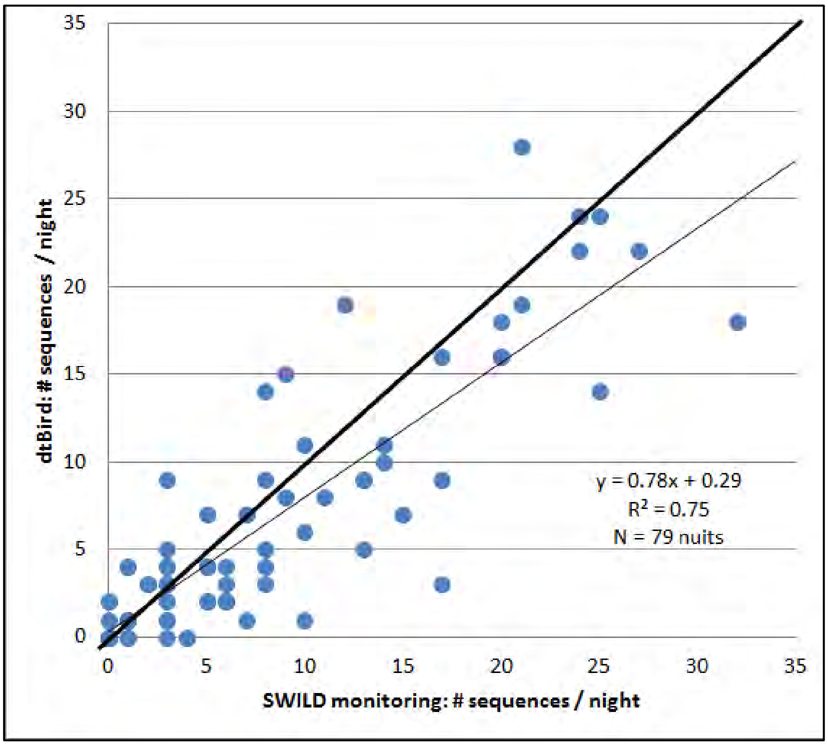

Fig. 7*: DTBat vs. SWILD monitoring at nacelle (119m).*

5.2 Comparison bat activity detection SWILD monitoring and DTBat system

Differences in bat detections using DTBat and SWILD detection units were not systematically. Bat activity clusters were reasonably represented using both system (*Fig. 8*)

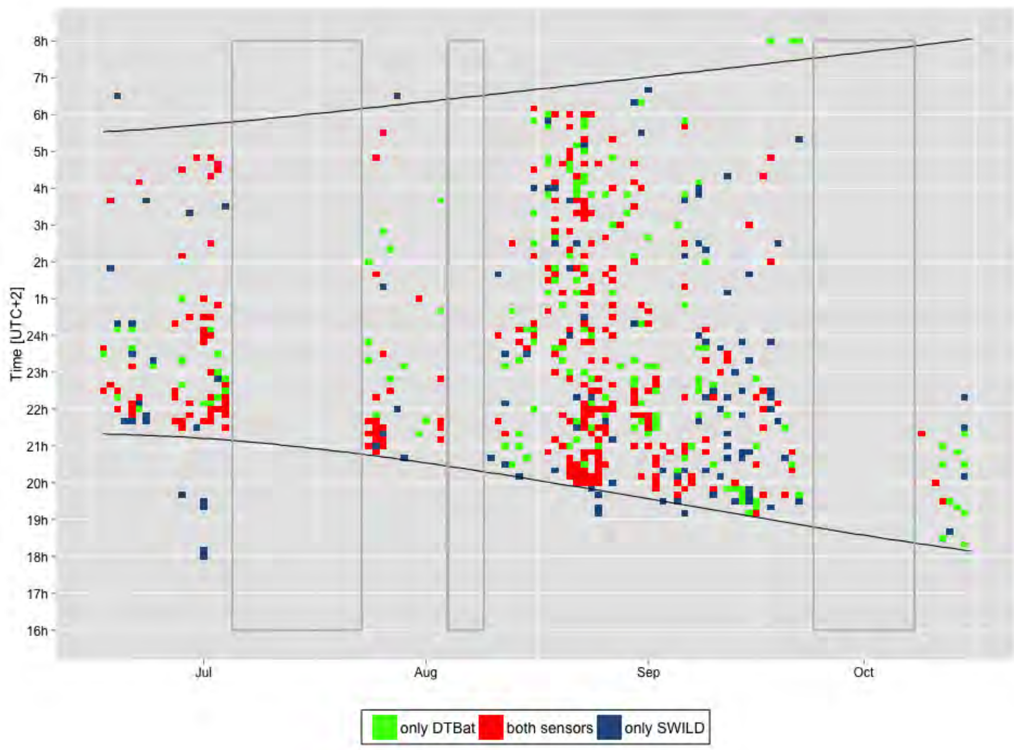

Fig. 8: *Bat passes detected by SWILD & DTBat in nacelle 119m compared for all 10min intervals*

6. Mitigation performance of the Fixed Environmental Stop Program

6.1 Fixed Environmental Stop Program by SWILD

- based on weather variables (wind speed, temperature, rain) which are adjusted by season and night time
- part of the operating approval and implemented the bat protection program since start of operation of WT Oldis of Calandawind

Settings

Stop program operational from 15 March - 31 May from **sunset plus 4 hours**:

- wind speed < 5.8 m/s and
- temperature > 2°C and

Stop program operational 1st June - 31 October from sunset to sunrise:

- wind speed < 5.8 m/s and
- temperature > 2°C and

The goal of the current Stop Program in operation at Oldis, Calandawind is to avoid ≥ 95% of bat collisions. It is assumed that this aim can be reached by stopping the wind turbine during periods corresponding to ≥ 95% of bat passes near the running turbine. (This aim refers to the bat activity measured in 2009. Because bat activity in 2014 was much lower compared to 2009, the relative reduction is less stringent in 2014).

In 2014 the bat activity covered by stop algorithm developed by SWILD was 91.48% (1353 out of 1479 bat passes were recorded during wind turbine stop). 1391 (94.05%) bat passes were recorded without power production; therefore they could not have faced a risk of collision because the blades did not move. Accordingly, the mortality rate is estimated at 5.95%. The target mortality rate of <=5% was not fully achieved (*Table 3*), however, because of the lower bat activity the absolute aim was more than reached (bat monitoring program 2014).

***Table 3**: Mitigation performance in relation to bat activity measured during the "full season" (15.03.2014-31.10.2014) using stop algorithm developed by SWILD*

Mitigation performance	2014	
	number of bat passes	[%]
Total bat activity	1479	100%
Bat activity, covered by stop algorithm	1353	91.48%
Bat activity while power production (running blades)	88	5.95%
Total bat activity without power production	**1391**	**94.05%**

7. Mitigation performance of the DTBat Stop Program

7.1 DTBat Stop Program

- based on the real-time detection of bats and the duration of the stop

Settings

Stop program operational from sunset to sunrise

- wind speed > 3m/s
- developed and tested in a period with mean bat activity (15.8 +- 1.8 seq./night)
- mitigation performance evaluated with data from SWILD detector at 119m

For the analyses of DTBat mitigation performance we calculated scenarios which differed in the following variables:

- DTBat detector [30m], [119m], [30m+119m]
- BP/Time: if the first (Pass1) or second (Pass2) bat sequence triggers the stop
- Stop Duration: duration of stop triggered by stop program, either 40min or 60min
- Time to Stop: estimated time until the blades are completely stopped:
  0s (theoretical minimum time possible: assumption that triggering bat is protected)
  7s (time used to record and analyse the signal and to forward DTBat stop trigger)
  14s (+ 7s, fastest shut-down of turbine so that blades do not harm the bats)
  37s (+30s, time used after pressing pause button at Vestas WT Oldis of Calandawind until the blades are completely stopped).
  52s (+45s, maximum time used from bat signal detected until blades are stopped).
- Delay d: time difference between DTBat and SWILD detection system: the final version contains only a single version: delay of SWILD detector by +15s compared to DTBat (which is synchronised by internet time).

DTBat (2015) evaluated different combinations of DTBat Stop Program settings with 1 to 3 bat passes (BP/Time) needed to trigger the stop signal and Stop Durations of 60min, 40min and 20min (*Table 4*). One scenario was evaluated with a time delay of 45s to completely stop the rotor blades. In our evaluation we concentrated on the four most promising scenarios (blue in *Table 4*).

Table 4: *Combination of DTBat Stop Program settings (DTBat, 2015) and the four main settings evaluated by SWILD (in blue square)*

BA (BP/Time)	Stop Duration (minutes)		
	60	40	20
1	X	X	X
2	X	X	X
3	X	X	X

None of the scenarios were able to completely reach the goal to cover at least 95% of bat activity*. The best mitigation performance was reached with 92.4% of total bat activity covered by using both detectors at 30 and 119m height.
These are still high values, especially if reached at sites with medium to low bat activity where the absolute mortality can be kept reasonable. A final appraisal on efficiency is needed in relation to the cost expressed as loss in energy production.

At nacelle height the mitigation performance was particularly sensitive to the Time to Stop. The performance decreased up to 9% points when the delay to stop the blades was more than 14s.

The Stop Duration generally improved the performance. However, this has to be evaluated in the light of the production loss.

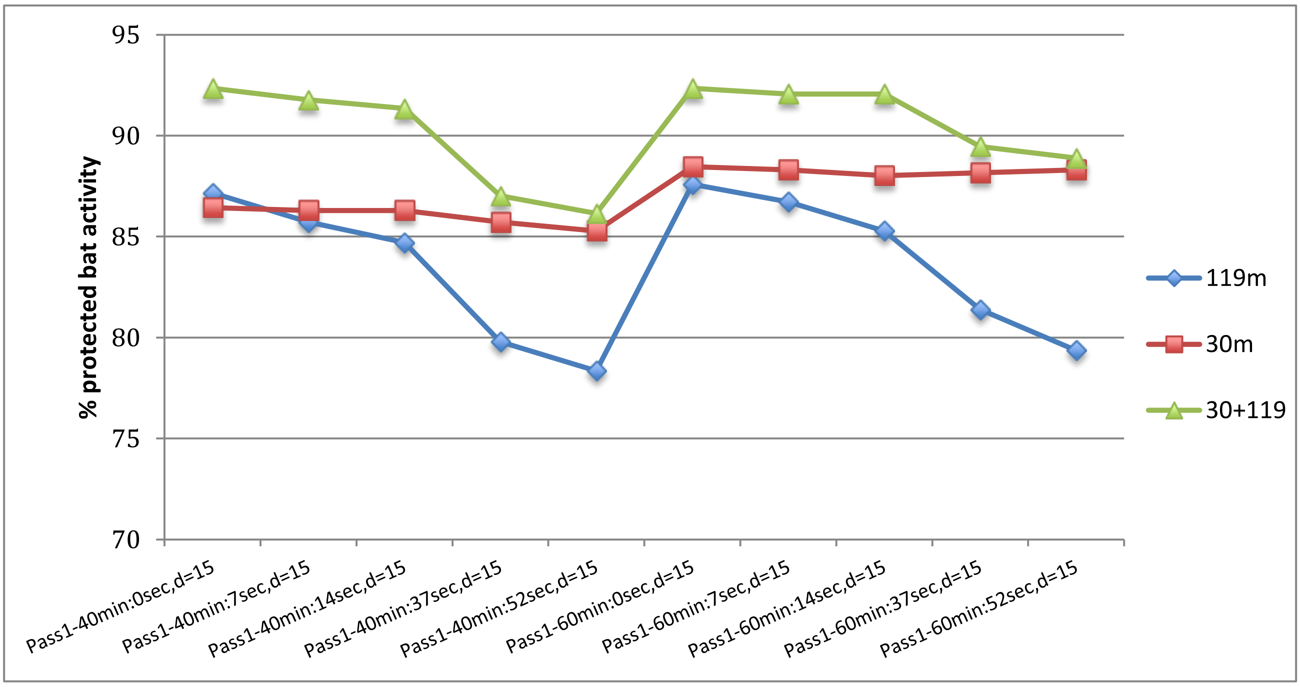

Fig. 9: *Mitigation performance of DTBat according to different scenarios using or multiple bat detectors on different heights.*

The mitigation performance was lower when 2 BP/Time or more delayed the stop of the WT. These scenarios were further apart from reaching the required rates of bats protected of more than 95%. Therefore we present only the scenarios with more than 1 bat pass to trigger the stop signal and removed the stop durations of 60min in our calculations.

*Attention: in difference to the values in the DTBat report, we calculated the total bat activity covered, including activity below 3m/s, because this refers to the mitigation aim decreed by the Cantonal authority.

7.2 Scenario DTBat detector [30m]

Scenario: (Pass1); Delay = 15s		seq. (wind speed ≥3 m/s)			total seq.		
Stop Duration	Time to Stop	# bat seq.	# bat seq. protected	% protected	# bat seq.	# bat seq. protected	% protected
40 min	0sec	272	178	65.44	693	599	86.44
	7sec	272	177	65.07	693	598	86.29
	14sec	272	177	65.07	693	598	86.29
	37sec	272	177	65.07	693	598	86.29
	52sec	272	176	64.71	693	597	86.15
60 min	0sec	272	192	70.59	693	613	88.46
	7sec	272	191	70.22	693	612	88.31
	14sec	272	191	70.22	693	612	88.31
	37sec	272	191	70.22	693	612	88.31
	52sec	272	190	69.85	693	611	88.17

7.3 Scenario DTBat detector [119m]

Scenario: (Pass1); Delay = 15s		seq. (wind speed ≥3 m/s)			total seq.		
Stop Duration	Time to Stop	# bat seq.	# bat seq. protected	% protected	# bat seq.	# bat seq. protected	% protected
40 min	0sec	272	183	67.28	693	604	87.16
	7sec	272	173	63.6	693	594	85.71
	14sec	272	166	61.03	693	587	84.7
	37sec	272	132	48.53	693	553	79.8
	52sec	272	122	44.85	693	543	78.35
60 min	0sec	272	186	68.38	693	607	87.59
	7sec	272	180	66.18	693	601	86.72
	14sec	272	170	62.5	693	591	85.28
	37sec	272	143	52.57	693	564	81.39
	52sec	272	129	47.43	693	550	79.37

7.4 Scenario DTBat detector [30m + 119m]

Scenario: (Pass1); Delay = 15s		(seq. wind speed ≥3 m/s)			total seq.		
Stop Duration	Time to Stop	# bat seq.	# bat seq. protected	% protected	# bat seq.	# bat seq. protected	% protected
40 min	0sec	272	219	80.51	693	640	92.35
	7sec	272	215	79.04	693	636	91.77
	14sec	272	212	77.94	693	633	91.34
	37sec	272	186	68.38	693	607	87.59
	52sec	272	182	66.91	693	603	87.01
60 min	0sec	272	219	80.51	693	640	92.35
	7sec	272	217	79.78	693	638	92.06
	14sec	272	217	79.78	693	638	92.06
	37sec	272	201	73.9	693	622	89.75
	52sec	272	197	72.43	693	618	89.18

8. Potential for optimisations of the current Fixed Environmental Stop Program

Table 5: *Energy production [MWh] and optimisation potential of the currently implemented Fixed Environmental Stop Program at the WT Oldis of Calandawind. Production loss [%] are related to month or full season (Total = 7.5 months) - not to annual production of the WT.*

Scenario / months	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Total
Energy production [MWh] without stop program	153.2	210.1	225.7	150.2	169.6	142.0	114.2	165.6	**1330.6**
Energy with ideal env. stop program	152.9	209.8	225.5	149.0	164.3	138.7	110.1	164.6	**1314.9**
Loss by ideal env. stop program	0.2	0.4	0.2	1.1	5.2	3.4	4.1	1.1	**15.7**
Loss by "ideal program" [%]	0.14%	0.18%	0.07%	0.73%	3.08%	2.38%	3.61%	0.64%	**1.18%**
Energy with fixed env. stop program	148.3	201.1	217.9	131.6	150.8	122.2	86.7	130.1	**1188.6**
Loss by fixed env. stop program	4.8	9.0	7.8	18.6	18.8	19.9	27.5	35.6	**141.9**
Loss by "fixed program" [%]	3.16%	4.30%	3.45%	12.37%	11.08%	13.99%	24.05%	21.48%	**10.67%**

The Fixed Environmental Stop Program (fixed program) is based on few weather parameters (temperature, wind and rain) which are roughly fixed for season and time. Currently, the rainfall is not yet implemented in the stop program.

We evaluated the potential to optimize the currently implemented fixed program by more environmental parameters, a better estimation for seasonal bat activity or an improved multivariate model (Complex Environmental Stop Program).

The realised energy production using the Fixed Environmental Stop Program was 1188.6 MWh from March to October 2014 (*light blue* in Fig. 10). For these summer months this resulted in an average production loss of 10.7% (*Table 5*). The potential for optimisation by an improved Stop Program which still covers the necessary bat protection promises a supplement of up to 126.3 MWh (additional 9.5% of total, *dark blue*). These calculations result in a minimal energy loss of 15.7 MWh (*red*, 1.18%) when we apply the theoretically best mitigation program which still fully covers the protection of the bats (*Table 5*).

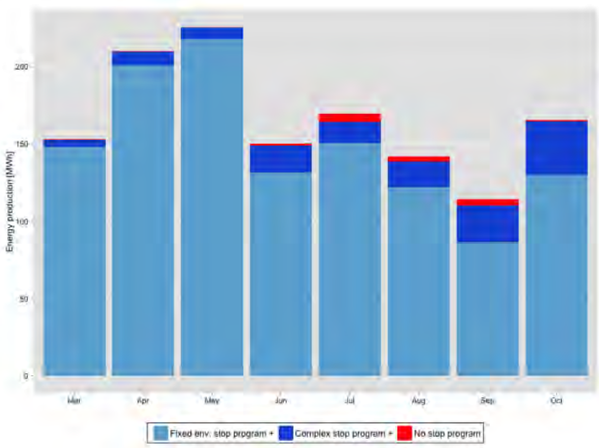

***Fig. 10**: Potential for optimisation in energy production under the current and ideal Stop Programs.*

9. Loss in energy production by the Fixed Environmental Stop Program

The performance of the Fixed Environmental Stop Program during the full season 2014 is presented in Fig. 11.

In 56% of the night time (7’889 intervals of a total of 14’096) the criteria of the stop program was fulfilled. In 12 % of the time (1’711 intervals) the WT was standing for other reasons (e.g. technical) resulting in a total of 68% of the time where the WT was not running (9’600 intervals).

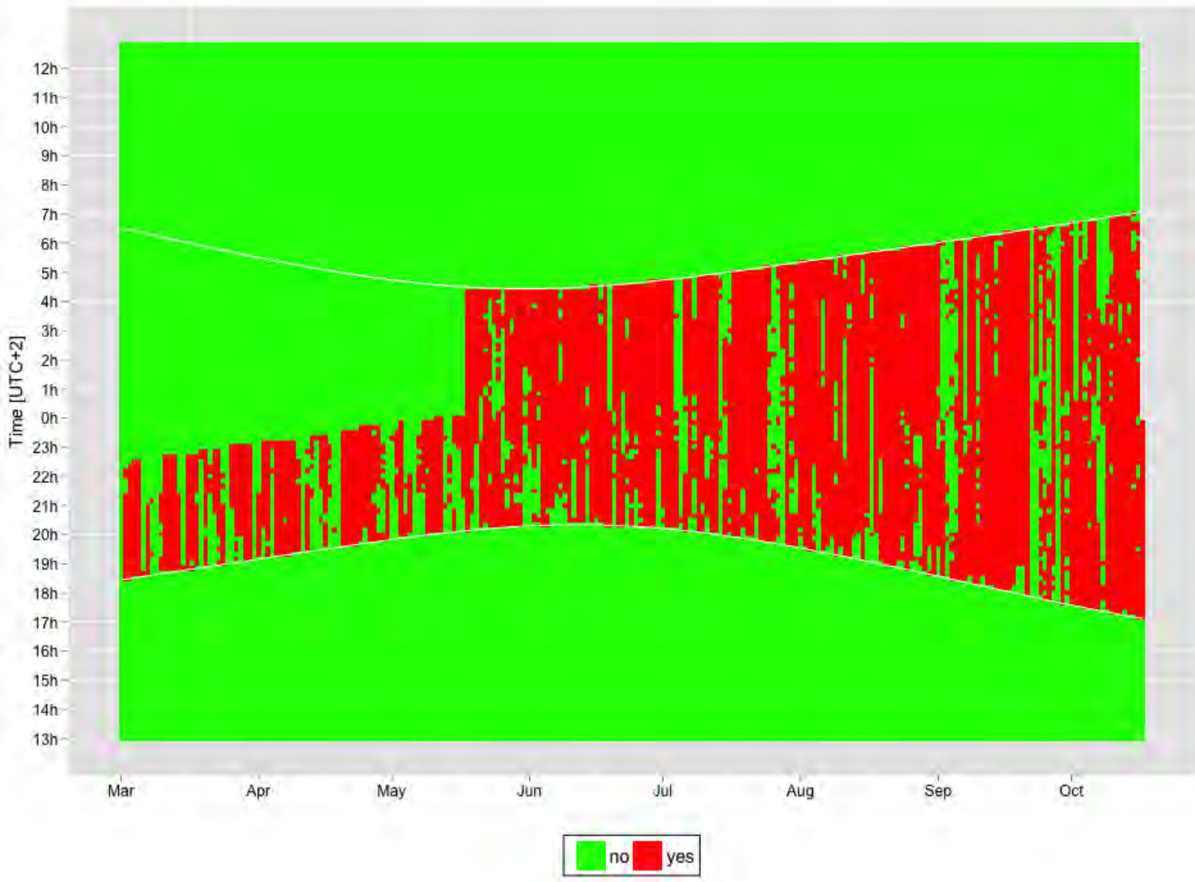

Fig. 11. *Control output of the Fixed Environmental Stop Program during the full season 2014. The criteria of the stop plan was fulfilled in 68% of the time between sunset and sunrise (10min intervals marked red), in the rest of the time of the night the WT was running (green).*

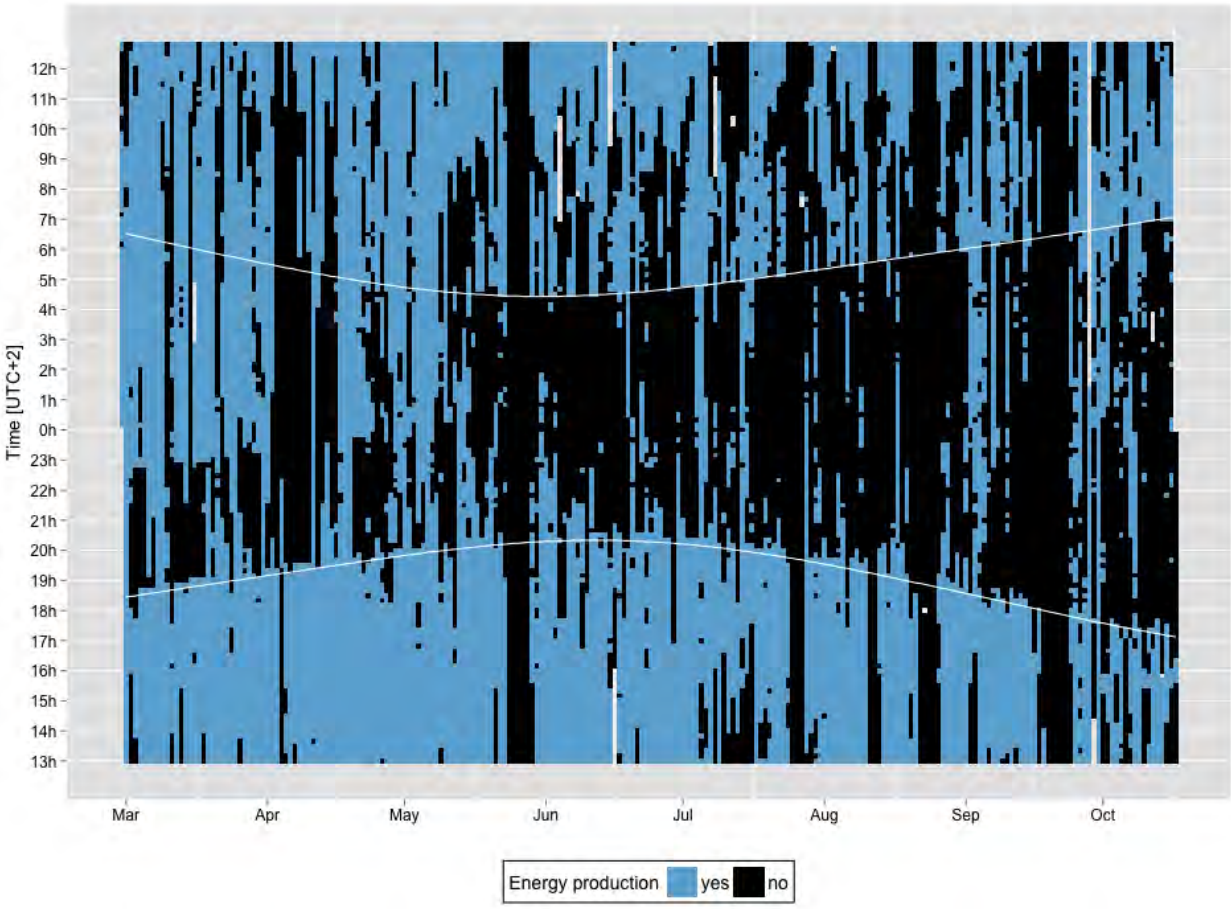

***Fig. 12**. Overview of energy production during the full season 2014 (blue=energy production, black=no energy production - composed of halts because of the stop program, technical issues & periods without wind).*

The total energy loss by the Fixed Environmental Stop Program during the “assessment period” was 54.3MWh, corresponding to **9.5%** of total energy production in this period (*Table 6*).
This high amount of loss in energy production is partly explained by the fact that the assessment period was in the middle of the migrating season of bats, and therefore in the period with highest bat activity.

The total energy loss in the “full season” was 143.9MWh, corresponding to **4.7 %** of total energy production in this period (*Table 6*).

For the calculation of total production loss per year we used expected mean energy production of 4.5 GWh for the year 2014. According to this reference the total loss in energy production by the Fixed Environmental Stop Program was **3.2%** (*Table 6*).

Table 6: *Potential energy production and energy loss by the Fixed Environmental Stop Program* during the various periods in 2014.*

	Potential Energy Production	Fixed Environmental Stop Program (stops 17h-7h)	Loss	
Time period	24 h [MWh]	24 h [MWh]	total [MWh]	24 h [%]
Assessement period	569	514.7	54.3	9.5%
Full season	3051	2907.1	143.9	4.7%
Year 2014	4500		143.9	3.2%

* The mitigation performance of the Fixed Environmental Stop Program in 2014 was 91.48% (without including stops by other causes).

10. Loss in energy production by DTBat—Stop Programs

Energy production loss using DTBat Stop Program mostly depending on stop duration (40min or 60min) after first bat activity (Pass1) was registered.

10.1 Scenario DTBat detector [30m]

Scenario: (Pass1); Delay = 15s		Total activity	Potential Energy Production		DTBat(r) Stop Program	Loss		
Stop Duration	Time to Stop	protected [%]	24 h [kWh]	18h-8h [kWh]	24 h [kWh]	total [kWh]	24 h [%]	18h-8h [%]
40 min	0s	86.44	568975	211281	525373	43602	7.66%	20.64%
	7s	86.29						
	14s	86.29						
	37s	86.29						
	52s	86.15						
60 min	0s	88.46			516960	52015	9.14%	24.62%
	7s	88.31						
	14s	88.31						
	37s	88.31						
	52s	88.17						

10.2 Scenario DTBat detector [119m]

Scenario: (Pass1); Delay = 15s		Total activity	Potential Energy Production		DTBat(r) Stop Program	Loss		
Stop Duration	Time to Stop	protected [%]	24 h [kWh]	18h-8h [kWh]	24 h [kWh]	total [kWh]	24 h [%]	18h-8h [%]
40 min	0s	87.16	568975	211281	556604	12371	2.17%	5.86%
	7s	85.71						
	14s	84.7						
	37s	79.8						
	52s	78.35						
60 min	0s	87.59			551508	17467	3.07%	8.27%
	7s	86.72						
	14s	85.28						
	37s	81.39						
	52s	79.37						

10.3 Scenario DTBat detector [30m+119m]

Scenario: (Pass1); Delay = 15s		Total activity	Potential Energy Production		DTBat(r) Stop Program	Loss		
Stop Duration	Time to Stop	protected [%]	24 h [kWh]	18h-8h [kWh]	24 h [kWh]	total [kWh]	24 h [%]	18h-8h [%]
40 min	0s	92.35	568975	211281	521399	47576	8.36%	22.52%
	7s	91.77						
	14s	91.34						
	37s	87.59						
	52s	87.01						
60 min	0s	92.35			511966	57009	10.02%	26.98%
	7s	92.06						
	14s	92.06						
	37s	89.75						
	52s	89.18						

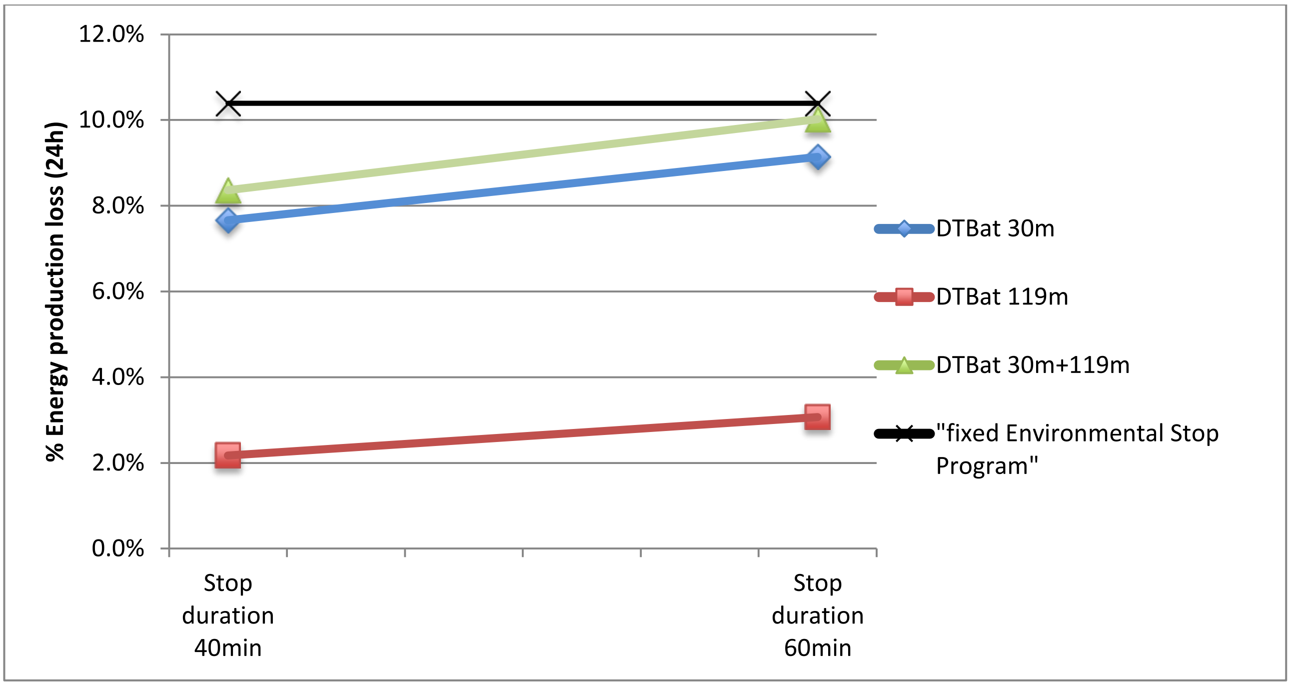

***Fig. 13**: Percentage of energy production loss using different stop durations and compared to energy production loss using current Fixed Environmental Stop Program*

An overview on the performance of the various scenarios in relation to energy loss is given in Fig. 14. It is visible that the reference scenario of the Fixed Environmental Stop Program from SWILD results in a high amount of bats protected (91.5%) but at relative high costs (9.5% of energy loss for the assessment period).

From the DTBat Stop Plans the best relation shows the scenario using both detectors at 30 and 119m height, with stop duration of 60min (top right orange cross in Fig. 14). However, there is considerable uncertainty related to the performance depending on the Time to Stop. Under the most optimistic assumption of 7s until complete shut-down it would protect an amount of 92.1% of bats. Under this most conservative assumption with a Time to Stop of 52s the performance reaches 89.2% of bats protected at a cost in energy loss of 10%. The reality lies somewhere between these scenarios marked by the horizontal line.

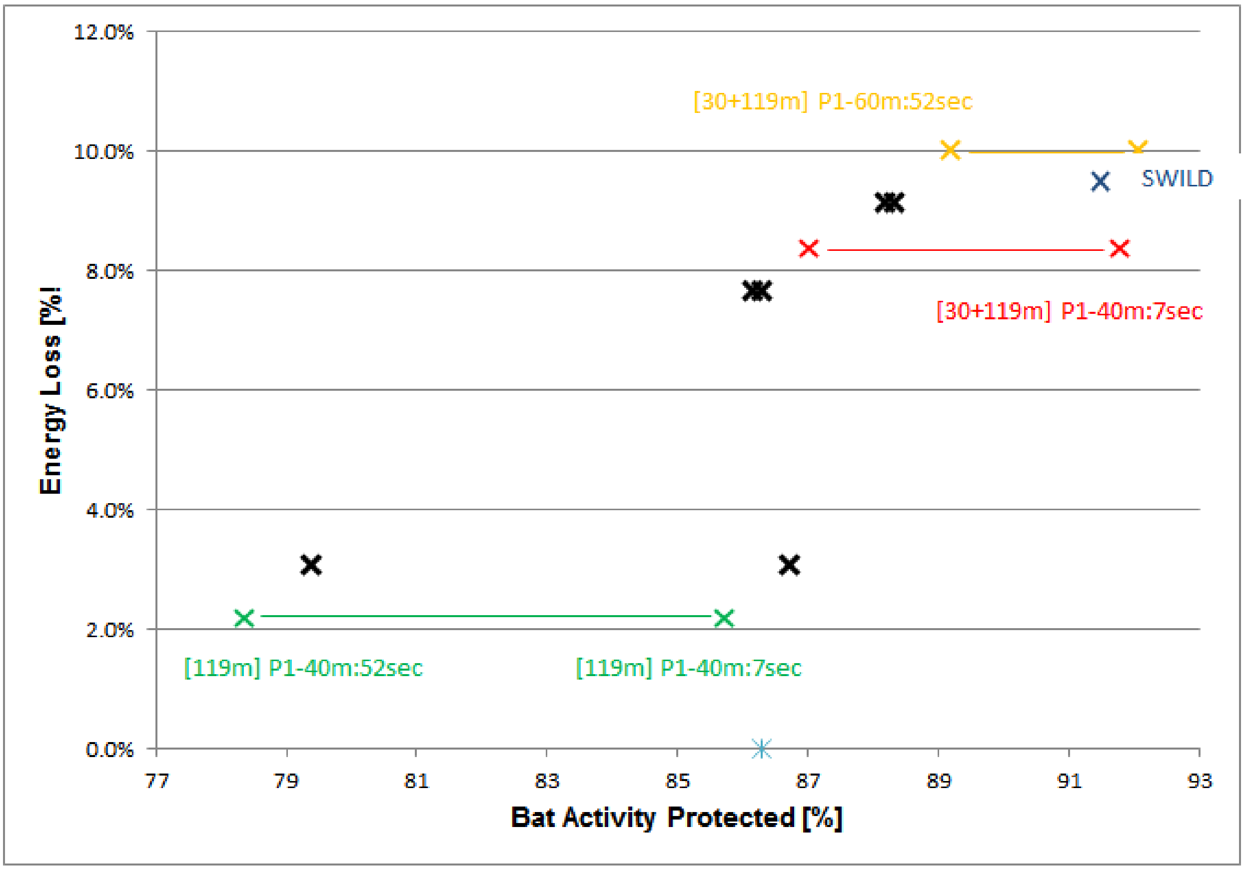

***Fig. 14**: Relation between Bat Activity Protected by a Stop Plan and Energy Loss (percentages are given for the "assessment period"). The 12 main scenarios are marked. Horizontal lines indicate uncertainty in relation of the effectivity, depending on the "Time to Stop" (left cross with "Time to Stop" 52s, right cross with 7s).*

10.4 Potential for optimisations of DTBat stop algorithm

- If it would be possible to protect already the first bat passing, the mitigation performance of DTBat might be reach very high values.
- The delay of 7s until to the output of the trigger signal could possibly be improved.
- The time needed to completely stop the rotors blades of WT at any wind speed should be investigated further.
- Because of systematic differences between detectors we suggest to assess the mitigation performance by an independent system.
- The availability of bat data from a full season would support an analysis for a broader generalisation. However, because of difference in local bat activities and species composition the performance of new systems as DTBat should be evaluated at multiple sites.
- Finally, it should be evaluated if a combination of real-time bat detection system and a stop program based on environmental parameters might be the most efficient solution.

11. References

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Brinkmann, R., Schauer-Weisshahn, H., & Bontadina, F. 2006. Untersuchungen zu möglichen betriebsbedingten Auswirkungen von Windkraftanlagen auf Fledermäuse im Regierungsbezirk Freiburg. Regierungspräsidium Freiburg, 66 p.

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12. Appendix

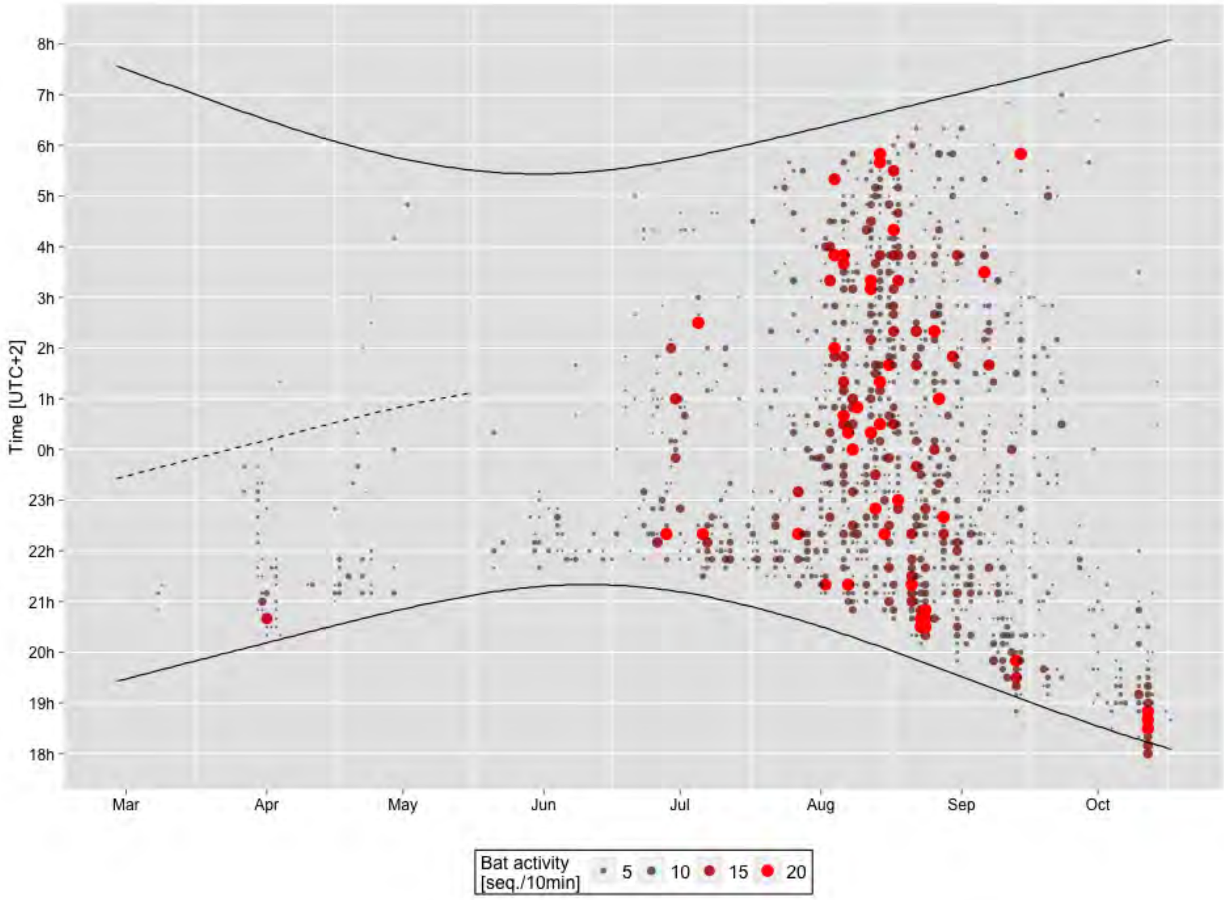

Fig. A1*: Bat activity in 2013 at nacelle 120m*

Table A1*: Comparison no. of bat passes within three seasons in Haldenstein Oldis*

season	date	#bat passes 2014	#bat passes 2013	#bat passes 2010
spring	15. Mar 14 - 31. May 14	123	147	690
summer	01. Jun 14 - 15. Aug 14	534	827	2522
autumn	16. Aug 14 - 31.Oct 14	822	4324	1694
total	15. Mar 14 - 31.Oct 14	**1479**	**5298**	**4906**

Table A2: Number of bat passes found for species / species groups at WT Oldis of Calandawind in 2014*. At least 7 bat species were identified in 14 species groups. Status according to the Swiss red list is indicated: orange: vulnerable (VU); yellow: near threatened (NT), grey: least concern (LC), data deficient (DD). Data from the "full season" period (N = 196 nights).*

	bat species	Oldis, Haldenstein				
# species	**species group**	**status red list**	**priority GR**	**migration**	**Total**	
					# bat passes	%
x	Natterer's Bat (*Myotis nattereri*)	NT			1	0.1%
	cluster Myotis: all Myotis supspecies	LC - EN			2	0.1%
x	Noctule (*Nyctalus noctula)*	NT			210	14.2%
x	Particoloured Bat (*Vespertilio murinus*)	VU			30	2.0%
	cluster NycVes: #Lesser Noctule, Noctule, Particoloured Bat *(Nyctalus leisleri, Nyctalus noctula, Vespertilio murinus)*	NT - VU	#		327	22.1%
	cluster Nycmi: #Lesser Noctule, Serotine, Particoloured Bat *(Nyctalus leisleri, Eptesicus serotinus, Vespertilio murinus)*	NT - VU	#		74	5.0%
	cluster Nyctaloid: Noctule& #Lesser Noctule, Serotine, Particoloured Bat & #Northern Bat *(Nyctalus noctula, Nyctalus leisleri, Eptesicus serotinus, Vespertilio murinus, Eptesicus nilssonii)*	NT - VU	#		429	29.0%
x	Common Pipistrelle (*Pipistrellus pipistrellus)*	LC			172	11.6%
x	Pygmy Pipistrelle (*Pipistrellus pygmaeus*)	NT			4	0.3%
	cluster Pygmy-, Common Pipistrelle-, Common Bentwing Bat (*Pipistrellus pygmaeus, Pipistrellus pipistrellus & Miniopterus schreibersii*)	LC - EN			2	0.1%
x	cluster Nathusius' Pipistrelle- & Kuhl's Pipistrelle (*Pipistrellus nathusii & Pipistrellus kuhlii)*	LC			121	8.2%
	cluster Pipistrelle: all Pipistrelle supspecies (*Pipistrellus species)*	LC - NT			4	0.3%
x	#Savi's Pipistrelle (*Hypsugo savii*)	NT	#		63	4.3%
	cluster Nathusius'-, Kuhl's-, & #Savi's Pipistrelle (*Pipistrellus nathusii, Pipistrellus kuhlii & Hyposugo savii*)	LC- NT	#		13	0.9%
	species: bat; species unknown	LC - CR			26	1.8%
7	**Total**				**1479**	**100.0%**

13. Glossary

Activity(bat activity): number of bat passes (series of bat calls) recorded per time.

Assessment period: Period with access to wind data used for estimations of mitigation performance and energy production losses (11.8 – 31.10.2014). Total 81 nights, outage 6 nights, N=75 nights of operation

Bat pass (BP) a series of bat calls recorded when a bat is in the detection range of the microphone. It is a measure of activity and may include the same individual approaching the detector several times. It is used as a measures how exposed bats are to wind turbines

BP/Time number of bat passes (in the stop duration) used to trigger the stop: first BP is indicated with Pass1 in the modelling scenarios

Call: single call of a bat, mostly in the ultrasound range

Delay d: time difference between DTBat and SWILD detection system: the SWILD detector is delayed by +15s compared to DTBat (which uses internet time)

Fixed Environmental Stop Program: program to stop the wind turbine based on simple environmental parameters; part of the operating approval for Calandawind aimed to reduce bat mortality.

Full season: Standardized recording SWILD: 15.3. – 31.10.2014, with some outages because of technical issues from 21.-27.03, 19.7-6.8 and 7.10-22.10. Total 230 nights, N=196 nights of operation.

Mitigation performance: Performance of the system measured in the amount of bats not exposed to running blades.

Outage: Periods without bat detection because of technical issues (bat detector failed or wind turbine was not in operation, e.g because of service)

Species group: cluster of bat species, which can not be separated based on bioacoustics

Stop Duration duration of stop of the wind turbine triggered by stop program (40 or 60min)

Study period Simultaneous recording period of DTBat & SWILD: 1.7 – 31.10.2014 (123 nights*) for comparisons of bat activity and recording systems. Wind turbine was out of service during this period for 6 nights. Total N=117 nights of operation.

Time to Stop: estimated time until the blades are completely stopped:

- 0s (theoretical minimum time possible: assumption that triggering bat is protected)
- 7s (time used to record and analyse the signal and to forward DTBat stop trigger)
- 14s (+ 7s, fastest shut-down of turbine so that blades do not harm the bats)
- 37s (+30s, time used after pressing pause button at Vestas WT Oldis of Calandawind until the blades are completely stopped – measured by SWILD at 6m/s wind speed).
- 52s (+45s, maximum time used from bat signal detected until blades are stopped, DTBat report 2015).

WT Wind Turbine