BEFORE AN EXPERT PANEL
SOUTHLAND WIND FARM PROJECT

Under the	**FAST-TRACK APPROVALS ACT 2024**
In the matter of	an application for resource consents, a concession, wildlife approvals, an archaeological authority and approvals relating to complex freshwater fisheries activities in relation to the Southland Wind Farm project
By	**CONTACT ENERGY LIMITED**
	Applicant

SOUTHLAND WIND FARM TECHNICAL ASSESSMENT #6: LONG-TAILED BAT EFFECTS

GERARDUS KESSELS AND IAN DAVIDSON-WATTS

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EXECUTIVE SUMMARY

1. The long-tailed bat / pekapeka has a conservation status of Threatened – Nationally Critical. Prior to our investigations in relation to the Southland Wind Farm, existing long-tailed bat populations were known to be present approximately 10-20 km to the southeast of the Wind Farm Site in the Catlins Forest Parks. The Wind Farm Site itself was not previously a known location for long-tailed bats.[1]

2. Dr Davidson-Watts (of Davidson-Watts Ecology Ltd) undertook extensive bioacoustics surveys across the Wind Farm Site between December 2022 and April 2024.

3. The results of those extensive surveys (and subsequent statistical analysis by data modelling consultancy Proteus) indicate that:

    (a) the Wind Farm Site is used for foraging and commuting, but is not likely core habitat for a local maternity population of long-tailed bats;

    (b) bat detection levels are comparatively very low in overall terms, particularly compared to other known areas with bats in the Catlins;

    (c) there is a general preference for tall vegetation (exotic plantation forest or wilding conifers) and areas close to rivers, wetlands and tracks;

    (d) bat activity on or near the Wind Farm Site is focussed along the escarpment between Matariki Forest and the adjacent Catlins Conservation Park (this area being identified as the **Bat Risk Area**). There are 11 wind turbines proposed in this area;

    (e) the risk of blade strike over the majority of the Wind Farm Site is very low due to the low bat activity and the high altitude of the turbine locations, however there is a moderate strike risk at proposed turbines MAT-01, MAT-02, MAT-03, MAT-04, MAT-06, MAT-07, MAT-12, MAT-16 and MAT-17) (these turbines being located within the Bat Risk Area);

    (f) bat activity is highest over the autumn months of mid-February to mid-April;

[1] This report focuses on long-tailed bats. The closest documented short-tailed bat population is in the upper Eglinton Valley in Fiordland, almost 200km away from the Wind Farm Site. The vegetation on the site would likely not support the needs of this species and they were not detected during the bioacoustics monitoring for long-tailed bats.

(g) bat activity declines with rainfall and as wind speed increases (noticeably when speeds are greater than 5 m/sec as modelled at the wind turbine hub height); and

(h) bat activity increases with temperature increases (being most active at temperatures >8°C).

4. Potential adverse effects from the Project include habitat removal, habitat displacement, turbine strike and/or barotrauma.[2]

5. Adverse effects from construction are likely to be negligible as the site is only occasionally used by bats and unlikely to contain roosting habitat.

6. All experts involved in the previous COVID-19 Recovery (Fast-track Consenting) Act 2020 (**Covid Fast-track**) process for the Project agreed that sufficient data had been obtained to inform management measures and conditions. The Department of Conservation (**DOC**) commented that the data obtained was of very high quality and should be the standard for wind farm developments.

7. Through the expert-led discussions during the Covid Fast-track process, a suite of measures to address the Project's potential and actual effects on long-tailed bats were agreed, including in particular:

(a) a curtailment regime for the nine turbines identified in paragraph 3(e) and Figure Long-tailed Bats-10 (Part G);

(b) an extensive scheme to provide compensation for any residual effect of turbine strike or habitat displacement on long-tailed bats; and

(c) post-construction monitoring.

8. The curtailment regime is based on trialling 'live curtailment' for those nine turbines listed in paragraph 3(e), for an initial operating period of up to three years, with specific details as follows:

(a) if monitoring shows that live curtailment is effectively managing adverse effects and the technology is robust, live curtailment will continue, however;

(b) if monitoring shows that live curtailment is not effectively managing adverse effects (including if the technology is not considered sufficiently

[2] Where bats are affected by the change in air pressure in close proximity to the turbines.

robust), live curtailment should cease and set curtailment should be implemented from sunset to sunrise for the following parameters;

(i) between 15 February and 15 April when;

(ii) windspeed is 5 m/sec or lower at hub height; and

(iii) temperature is 8°C or higher; and

(iv) precipitation is less than 1.5 mm/hour.

9. Contact proposes the compensation scheme that was agreed with DOC through the Covid Fast-track process, to address any residual effects of turbine strike or habitat displacement on long-tailed bats. Contact will make an initial payment to DOC of $300,000, and annual payments of $150,000 (CPI adjusted) thereafter for the life of the windfarm, to fund an intensive ground-based predator control programme within a 10,000 ha area in the Beresford Range. This will significantly benefit the long-tailed bat population within the Catlins Forest and Beresford Range in particular, and more than adequately compensate for the residual risk of turbine strike mortality and displacement of bat habitats within the Wind Farm Site. The animal pest control programme will also have substantial benefits to the indigenous forest, including many threatened and at-risk fauna species. Mohua / yellowhead, in particular, will significantly benefit from the animal pest control, and we understand this species will be monitored by DOC to ensure the efficacy of the animal pest control programme (also as to serve as a proxy for bats).

10. Post commissioning bioacoustic monitoring is recommended to determine levels of bat activity around turbines and to allow refinement and review of the wind turbine curtailment regime at the identified nine wind turbines within the Bat Risk Area. Again, this is as agreed with the other experts involved in the Covid Fast-track process.

11. Detailed methodologies for the bat compensation approach, the other measures proposed to address effects on long-tailed bats, and the monitoring regime will be set out in a Bat Management Plan (**BMP**).

12. Overall, the effects of the wind farm on long-tailed bats are localised, likely to be low and able to be mitigated (with residual effects able to be appropriately compensated). It is important to note that bat activity is, relative to other sites where bats are present in the Catlins, low, or very low over most of the Wind

Farm Site. A combination of effects management tools, and an extensive animal pest control program to address residual effects, will ensure that the potential adverse effects of the construction and operation of the Southland Wind Farm on long-tailed bats and their habitat are no more than minor. There will also likely be a net gain outcome for long-tailed bats in the Catlins.

INTRODUCTION

13. Our full names are Gerardus (Gerry) Henricus Anthonius Kessels and Ian Frank Davidson-Watts.

14. This technical assessment addresses the effects of the Southland Wind Farm project on long-tailed bats. Terrestrial ecology effects more broadly are covered in the Terrestrial and Wetland Ecology Report.

Qualifications and experience

15. Gerry Kessels has the following qualifications and experience relevant to this assessment:

    (a) A Bachelor of Science degree majoring in zoology (completed in 1988) and a Master of Resource and Environmental Planning (1st class honours, on wetland ecology - completed in 1999), both from Massey University.

    (b) A member of the New Zealand Ecological Society, the Ornithological Society of New Zealand, the Waikato Botanical Society, and an associate member of the New Zealand Planning Institute.

    (c) Certified with 'Bat Competency' by DOC as being suitably qualified to undertake and analyse data for bioacoustic surveys (using acoustic bat monitors (**ABM**)), identify long-tailed bat roosts and capture and handle long-tailed bats.

    (d) Over 34 years' professional experience as an ecologist. Managing director and principal ecologist of Kessels & Associates Limited since 1999 (trading as Kessels Ecology until 2018, and now trading as Bluewattle Ecology), as well as on retainer with SLR Consulting as Technical Director – ecology for the Asia-Pacific region.

    (e) He has project managed, peer reviewed, and been involved in numerous bat surveys and effect assessments on bats throughout New Zealand since 2005. He undertook ecological assessments for various wind farms, including Tararua Wind Farm, Te Uku Wind Farm, Hauāuru Mā Raki, Puketoi, Mt Cass, Poutoa, and Kaimai.

(f) He is currently acting as an independent peer reviewer of the monitoring programme on the consented and operational Waipipi (Waverly) Wind Farm and the consented Kaiwaikawe (aka Omamari) Wind Farm.

(g) Has appeared as an expert witness before council hearings, the Environment Court and a Board of Inquiry in relation to consent applications for infrastructure projects.

(h) Is an accredited Independent Hearings Commissioner certified by the Ministry for the Environment and Local Government New Zealand.

16. Ian Davidson-Watts has the following qualifications and experience relevant to this assessment:

(a) A PhD from (Bristol/Open University UK, 2007) in the ecology of bats and a Higher National Diploma in Conservation Management, Sparsholt College Hampshire (UK) 1996.

(b) Over 30 years' professional experience as a bat ecologist. Managing Director and technical lead for Davidson-Watts Ecology Ltd (UK) since 2013 and Davidson-Watts Ecology (Pacific) Ltd (NZ) since 2017. Ian has led bat surveys and assessments and obtained bat mitigation permits for the UK's largest infrastructure schemes including HS2 (225km) and Sizewell C Nuclear Power Station, and numerous urban expansions and road schemes.

(c) In New Zealand Ian is certified with 'Bat Competency' by DOC as being suitably qualified to undertake and analyse data for bioacoustic surveys (using ABMs), identify long-tailed bat roosts and capture and handle long-tailed bats, fit radio-tracking tags to short and long-tailed bats and fit bands to long-tailed bats. In addition, Ian is a certified trainer for all these bat related competencies.

(d) Ian has delivered the bat survey field work, including large scale acoustic and radio-tracking surveys, and data interpretation of for a range of wind farm projects in Southland, Otago and Waikato, and has been also engaged as a specialist bat consultant to deliver the radio-tracking of long-tailed bats for the Southern Links (Hamilton), and as a bat expert for Hearings for Auckland's North West Network (Notices of Requirements).

(e) Ian is the only non-employed DOC member of DOC's Bat Recovery Group, which manages a range of bat conservation programmes and provides advice for survey requirements and the assessment of effects. He has also undertaken training and field work for local communities/non-profits and has led radio-tracking of long-tailed bats in the Waitakere Ranges (Auckland), Whangārei and the Catlins.

(f) His publication record includes the Conservation Status of New Zealand's bats (DOC, 2022), threat assessments for Auckland Region and Otago Region, and six peer reviewed papers on bat ecology in International scientific Journals. He is author of the UK's bat survey guidelines for bat trapping and radio-tracking.

(g) Prior experience to commercial consultancy, Ian has been a senior manager/deputy CEO for Gore and Grey District Councils (Regulatory and Planning management roles), Head of Environment Department for British Forces in Cyprus, Head of Natural Environment (Ecology) for the UK Ministry of Defence and various regulatory roles in England's statutory nature conservation agency English Nature (now call Natural England).

Code of conduct

17. We confirm that we have read the Code of Conduct for expert witnesses contained in the Environment Court Practice Note 2023. This assessment has been prepared in compliance with that Code, as if it were evidence being given in Environment Court proceedings. In particular, unless we state otherwise, this assessment is within our area of expertise and we have not omitted to consider material facts known to me that might alter or detract from the opinions we express.

Purpose and scope of assessment

18. The purpose of this assessment is to assess the potential effects of the Southland Wind Farm project on long-tailed bats to inform the applications being made by Contact under the Fast-track Approvals Act 2024. Contact is not seeking Wildlife approvals in respect of bats through this process; our assessment is essentially to inform the application for resource consents.

19. The scope of the assessment includes:

   (a) describing the methodology adopted for the bioacoustics and radio tracking surveys and the effects assessment;

   (b) a review of the results of the bioacoustics and radio tracking survey data supplied by Davidson-Watts Ecology;

   (c) describing the potential effects on long-tailed bats and their habitats associated with construction and operation of the wind farm; and

   (d) recommendations on the measures required to support the application to avoid, remedy, mitigate, offset or compensate for adverse effects on long-tailed bats and their habitats.

Assumptions and exclusions in this assessment

20. Our assessment has been informed by:

   (a) bioacoustic surveys undertaken by Davidson-Watts Ecology between December 2022 and April 2024;

   (b) radio tracking surveys undertaken by Davidson-Watts Ecology between February and March 2024;

   (c) habitat mapping by Wildlands updated in 2025; and

   (d) discussions we had with other bat experts – Colin O'Donnell (DOC's expert advisor) and Georgia Cummings (the peer review expert appointed by the expert consenting panel) – during the previous Covid Fast-track consenting process.[3]

THE SOUTHLAND WIND FARM PROJECT

21. Contact Energy Limited (**Contact**) is seeking various approvals necessary for the construction, operation and maintenance of a wind farm in Slopedown, Southland (the **Project**). The Project includes up to 55 wind turbines and associated infrastructure.

22. The full project description for the Project is provided at section 6 of Part A to the substantive application documents. We do not repeat it in our assessment. We do refer throughout our report to the three different landholdings that make up the Wind Farm Site: Matariki Forest (the eastern

[3] FTC-SWF-expert-conferencing-JWS-ecology-bats.pdf and Bat-Expert-Conferencing-JWS-reconvened.pdf

part of the overall site), Jedburgh Station (the central part of the site, where most turbines are proposed) and Glencoe Station (to the west, where only three turbines are proposed).

LONG-TAILED BAT PRESENCE IN THE REGION

23. Once common throughout New Zealand, long-tailed bats numbers have declined markedly over the last 100 years (O'Donnell 2000). Although found patchily in the South Island, there is little detailed information on current trends or population sizes. However, it is likely that the South Island's populations of long-tailed bats are continuing to decline as a result of a combination of pressures such as competition and predation from invasive species (eg. Pryde et al. 2005; O'Donnell et al 2022).

24. The nearest recorded known population of long-tailed bats is in the Catlins Forest Park. More specifically, known long-tailed bat populations are reported approximately 10 km – 20 km to the east of the Wind Farm Site in the Thisbe and Catlins River Valley and Cairn Road area (DOC database, Catlins Bat Project and Davidson-Watts pers com).

25. In Southland, long-tailed bats occur in the Catlins, Stewart Island/Rakiura, Waikaia Bush and Fiordland (e.g. Eglinton Valley and Iris Burn), with sporadic records in other areas of extensive beech forest. However, only in the Eglinton Valley are populations actively monitored and subject to specific conservation action. There are sparse recordings of the species further afield, suggesting that, aside from Fiordland National Park, the Catlins is a likely stronghold for this species in the Southland region, with known roosting sites in locations such as the Tahakopa Scenic Reserve, approximately 25 km from the Wind Farm Site.

METHODOLOGY

26. Initial bioacoustic surveying was undertaken between December 2022 and June 2023 to identify whether long-tailed bats were present at the Wind Farm Site, and if so, the locations of bat activity. Following confirmation of bat presence, a significantly comprehensive bat study was devised in consultation with Proteus (an ecology-focussed statistics consultancy), and further bioacoustic surveys were undertaken over the period November 2023 to April 2024. In total eight bioacoustic surveys have been undertaken. This exceeds the level of pre-construction monitoring/survey undertaken on any other known wind farm project in New Zealand. This surveying has allowed a

statistically robust baseline from which an understanding of the climatic and habitat factors that influence long-tailed bat activity on the Wind Farm Site area can be determined.

27. Statistical analysis by Proteus helped inform our identification of the Bat Risk Area and parameters for set curtailment of operational turbines.

28. Two radio-tracking surveys were also undertaken to;

(a) confirm the assumption that bats are unlikely to be roosting on the Wind Farm Site, and;

(b) identify potential roost sites for compensation away from the Wind Farm Site

29. In the Covid Fast-track consenting process, there was agreement between the experts that:[4]

(a) the bioacoustic survey data was sufficient to:

(i) show long-tailed bats are present from time to time at the Wind Farm Site;

(ii) show that there are higher and lower use areas, and many turbine sites did not detect long-tailed bats (at the time of the surveys); and

(iii) describe the environmental conditions which are likely to be of higher risk to long-tailed bats;

(b) sufficient data has been gathered for specific management actions and certain conditions to be drafted; and

(c) although the sample size of the tracking study was small:

(i) it confirms that long-tailed bats are unlikely to be roosting in the Wind Farm Site (but non maternity roosts were found close to the Wind Farm Site); and

(ii) further radio tracking is not required to inform the mitigation strategy and management measures.

[4] FTC-SWF-expert-conferencing-JWS-ecology-bats.pdf at [17]–[18] and [23]–[25].

30. DOC's formal comments on the Covid Fast-track application included its view that:[5]

> "*The data on bat activity already collected by the applicants is of very high quality and the detail reflects what should be standard to assessing risks of specific windfarms to long-tailed bats*."

31. A summary of the methodology adopted in provided below. Further details, including any limitations, are provided in **Appendix One**.

Bioacoustics surveys

32. Between December 2022 and April 2024, Dr Davidson-Watts undertook eight bioacoustics surveys:

    (a) 29 December 2022 – 12 January 2023 (**survey 1**);

    (b) 30 January – 14 February 2023 (**survey 2**);

    (c) 7 – 23 March 2023 (**survey 3**);

    (d) 16 June – 24 August 2023 (**survey 4**);

    (e) 30 October – 30 November 2023 (**survey 5**);

    (f) 3 – 24 January 2024 (**survey 6**);

    (g) 20 February – 7 March 2024 (**survey 7**); and

    (h) 3 – 17 April 2024 (**survey 8**).

33. An additional ABM was also deployed at the top of the 80 m wind meteorological mast installed at the Wind Farm Site for two periods between November 2023 and March 2024.

34. The initial bioacoustic survey (29 December 2022 – 12 January 2023) deployed 20 ABMs in and around the Wind Farm Site and was designed primarily to determine whether bats were present at the Wind Farm Site. Over the next two surveys ABMs were deployed[6] in other habitats within the Wind Farm Site and near proposed turbine sites to understand the extent of the bat activity around the proposed wind farm more precisely.

[5] 25Jul24_Department-of-Conservation_FTC126_Comments-Received.pdf at [70].
[6] 20 ABMs were deployed in Survey 2 and 22 were deployed in Survey 4.

35. Survey 4, during the winter months of 2023, was undertaken to determine whether there were levels of bat activity which might suggest significant roosting sites or activity within the Wind Farm Site.

36. Surveys 5 – 8 undertaken over the 2023/24 summer and autumn enabled us to compile a comprehensive dataset of bat activity across the Wind Farm Site and to gain a greater understanding of the factors that influence bat activity in that area, and potential seasonal influences. These surveys were designed to take into account both the locations of the wind turbines and nearby potential bat foraging habitat (based on experience, data from surveys 1 – 4 and general literature on long-tailed bats). During these surveys, 80 ABMs were deployed during each survey period.

37. The locations of the ABMs are shown in Figure Long-tailed Bats-1 (Part G) for surveys 1 – 4 and Figure Long-tailed Bats-2 (Part G) for surveys 5 – 8. ABMs were designated labels L1 to L22 for surveys 1 to 3 and MW1 to MW17 for winter survey 4. Surveys 5 to 8 have been labelled as ABMs B01 to B80 and are arranged west to east across the site to enable easier identification. It should be noted that for surveys 1 to 3, while the ABMs were designated L1 to L22, some of the loggers were moved to different locations between surveys and therefore the ABM number for those surveys does not always identify as a fixed location.

Trapping and radio tracking

38. To complement the acoustic data set, Dr Davidson-Watts undertook trapping and radio tracking work to:

    (a) provide context of where the bats might be travelling from, or if they were located within the Wind Farm Site or adjacent bush areas; and

    (b) identify potential populations that could receive conservation management to compensate for any residual mortality effects from the Project.

39. Two survey sessions were undertaken:

    (a) **Radio tracking survey 1** involved four trapping nights – 21, 22, 26 and 27 February 2024 – near the Tawanui Campsite adjacent to the Catlins River.

(b) **Radio tracking survey 2** involved two trapping nights – 19 and 20 March 2024 – on the Wind Farm Site. Trapping locations were informed by the bioacoustic surveys where bat activity was highest, and the presence of suitable habitat. This resulted in the southern escarpment amongst tall exotic plantation being the priority for trapping sites.

Statistical analysis and modelling

40. Proteus undertook statistical analysis and modelling of the bioacoustic data collected during surveys 5 – 8, against the vegetation, terrain and weather factors influencing bat behaviour and habitat utilisation. The full Proteus report is included as **Appendix Four**.

41. The statistical analysis was conducted to enhance our understanding of the data concerning long-tailed bat activity at the Wind Farm Site. This analysis was also used to inform our recommendations regarding measures to address the potential impacts of the project, particularly in relation to the risks of turbine strikes and barotrauma.

42. Six generalised linear mixed models were fitted at three different temporal scales using two measures of bat activity, whether or not bats were detected and the total number of bat detections. For the presence-absence measure at all temporal scales, a binomial model was used. For the number of bat detections at all temporal scales, a 'Tweedie' model was used. For the session and nightly temporal scales, data for each ABM were aggregated across sampling sessions and night, respectively.

LONG-TAILED BAT PRESENCE AND HABITAT AT THE WIND FARM SITE

43. The results of the bioacoustics surveys and statistical modelling, together with the data from the radio tracking, indicate that long-tailed bats are present at the Wind Farm Site and in the general area of the Wind Farm Site, but the Wind Farm Site is not considered core to a breeding (nursery) population of long-tailed bats and the majority of the Wind Farm Site is not significant long-tailed bat habitat.

44. Long-tailed bat activity levels vary depending on the location and time of year. There is a pattern of consistently very low/no bat activity on Jedburgh Station, Glencoe Station and the western (lower elevation) part of the Matariki Forest, while there is low, but reasonably regular, activity on the eastern side of the Matariki Forest – close to the escarpment within the DOC conservation estate. There is also a pattern of increasing bat activity at a

greater number of ABM locations as summer progresses into autumn (mid-February – mid-April showed the highest level of activity). Other key factors for bat activity include:

(a) tall vegetation is associated with a higher level of bat activity across all models;

(b) bat activity is higher in areas that are close to rivers and tracks;

(c) bat activity declines with rainfall and as wind speed increases; and

(d) bat activity increases with temperature increases.

45. The bioacoustics surveys show that the pasture areas of the Wind Farm Site are largely utilised very occasionally and sporadically, and the Matariki plantations, while regularly utilised, are only utilised at very low detection rates, especially when compared to similar habitats elsewhere in the Catlins.

46. To put this into context, the highest single average number of bat passes detected for any ABM over the 2023/2024 survey period was 3.2 per night. For comparison, detection rates at other nearby sites in the Catlins locality recorded from November to the end of March as part of the Catlins Bat Project average 47.8 bat passes per night (based on 2021-22 data). The tracking data also suggest a comparatively small number of bats are roosting (solitarily) along the Slopedown Escarpment and mostly utilising habitat within the Wind Farm Site or foraging in late summer/autumn. This all strongly suggests the Wind Farm Site is not core habitat for the local population of long-tailed bats.

47. Analysis of the bioacoustic survey data allows a fine grained approach for determining the ecological value of the differing habitat types in each locality for long-tailed bats. This analysis confirms that habitats in the eastern part of the Matariki Forest appear to provide significantly more value to long-tailed bats compared to the rest of the Wind Farm Site.

48. Using this fine grained approach, it is considered appropriate to differentiate between these localities based on the data and the quality of the habitat, given that bat activity is considerably lower (50 times less) within the pasture dominated areas of Jedburgh Station and Glencoe Station than through the escarpment areas of Matariki Forest (predominantly plantation forestry). In this light:

(a) the Jedburgh and Glencoe sites are of Low ecological value for bats;

(b) the intended locations for turbines MAT-01, MAT-02, MAT-03, MAT-04, MAT-06, MAT-07, MAT-12, MAT-16 (and potentially in the future at MAT-17) at Matariki are in, or close to, areas of High bat habitat value (where highest bat activity occurred close to the escarpment and in areas where there were very old pine trees (and less so at the younger pine and Douglas fir trees)); and

(c) the remaining turbine sites in Matariki are of Moderate ecological value for bats.

49. Given the relationship between long-tailed bat activity and taller vegetation, the habitat value may change over the life of the Project in response to changes in forestry management.[7]

50. Key findings from the bioacoustic and radio-tracking surveys are set out below.

Initial bioacoustic surveys 2022/2023 (Surveys 1-3)

51. 1548 bat passes were recorded at the 31 locations deployed within the Wind Farm Site over a total of 656 recorder nights (being the sum of all nights recorded at all ABM locations). Activity was highest at ABM L14 and also relatively high along the eastern edge of the Matariki Forest (referred to as the Matariki escarpment), as shown in **Table 1** below. The overall average (mean) bat activity was:

(a) 2.36 bat passes per night for the data collected within the Wind Farm Site, including L14 (where 1275 (or 82%) of the 1548 bat passes were recorded);

(b) 0.45 bat passes per night for data collected within the Wind Farm Site, excluding L14; and

(c) 0.19 bat passes per night for data collected within the Wind Farm Site when the data from all the loggers along the eastern edge of the Matariki Forest (i.e. the Matariki Escarpment ABMs) are removed.

[7] FTC-SWF-expert-conferencing-JWS-ecology-bats.pdf at [31].

Table 1: Total and average bat pass detection rates for surveys 1 – 3

Surveys 1 – 3	Nights	Bat passes	Bat pass/night
Whole site	656	1548	2.36
L14 only	46	1275	27.72
Matariki escarpment	138	1447	10.49
Matariki escarpment (excluding L14)	92	172	1.87
Whole site (excluding L14)	610	273	0.45
Whole site (excluding Matariki escarpment)	518	101	0.19

52. **Table 2** below provides summary data of long-tailed bat activity at each ABM location and **Table 3** below provides the percentage of nights long-tailed bats were detected at each ABM location.

53. A mapped summary of total bat passes at ABM locations over surveys 1 – 4 is shown in Figure Long-tailed Bats-3 (Part G). Figure Long-tailed Bats-4 (Part G) illustrates the ABMs which recorded more than 20 bat passes per survey during surveys 1 – 3.

Table 2: Summary of long-tailed bat activity at ABM locations during surveys 1 – 3[8]

ABM	Total bat passes Jan 23	Nights	Bat passes per night Jan 23	Total bat passes Feb 23	Nights	Bat passes per night Feb 23	Total bat passes March 23	Nights	Bat passes per night March 23
L1	0	16	0.00	1	17	0.06	0	12	0.00
L2	0	16	0.00	4	17	0.24	0	15	0.00
L3	0	15	0.00	1	17	0.06	9	6	1.50
L4	0	15	0.00	1	17	0.06	2	15	0.13
L5	9	15	0.60	Failed			10	14	0.71
L6	0	15	0.00	0	15	0.00	2	13	0.15
L7	0	15	0.00	0	13	0.00	11	10	1.10
L8	41	15	2.73	0	17	0.00	5	14	0.36
L9	0	15	0.00	5	15	0.33	0	15	0.00
L10	2	16	0.13	0	3	0.00	1	14	0.07
L11	46	15	3.07	36	15	2.40	4	16	0.25
L12	0	15	0.00	3	15	0.20	19	9	2.11
L13	0	15	0.00	3	15	0.20	9	14	0.64
L14	696	15	46.40	309	15	20.60	270	16	16.88
L15	11	15	0.73	21	15	1.40	54	16	3.38
L16	0	15	0.00	1	15	0.07	2	16	0.13
L17	0	15	0.00	0	12	0.00	0	16	0.00
L18	0	15	0.00	0	15	0.00	1	16	0.06
L19	0	15	0.00	2	15	0.13	23	16	1.44
L20	0	15	0.00	2	15	0.13	0	16	0.00
L21	No survey			No Survey			0	1	0.00
L22	No survey			No Survey			0	7	0.00

[8] The 22 ABMs were not always placed at the same location for each of the surveys. The locations are shown in Figure Long-tailed Bats-1 (Part G)

Table 3: Percentage of nights long-tailed bat were detected at ABM locations during surveys 1 – 3

ABM	Survey nights	No. Nights bats detected Jan 23	% of survey nights bats encountered	Survey nights	No. Nights bats detected Feb 23	% of survey nights bats encountered	Survey nights	No. Nights bats detected March 23	% of survey nights bats encountered
L1	16	0.00	0	17	1.00	6	12	0.00	0
L2	16	0.00	0	17	2.00	12	15	0.00	0
L3	15	0.00	0	17	1.00	6	6	1.00	17
L4	15	0.00	0	17	1.00	6	15	1.00	7
L5	15	3.00	20	Failed	Failed	0	14	7.00	50
L6	15	0.00	0	15	0.00	0	13	1.00	8
L7	15	0.00	0	13	0.00	0	10	6.00	60
L8	15	6.00	40	17	0.00	0	14	4.00	29
L9	15	0.00	0	15	2.00	13	15	0.00	0
L10	16	1.00	6	3	0.00	0	14	1.00	7
L11	15	7.00	47	15	7.00	47	16	2.00	13
L12	15	0.00	0	15	2.00	13	9	5.00	56
L13	15	0.00	0	15	2.00	13	14	6.00	43
L14	15	12.00	80	15	11.00	73	16	12.00	75
L15	15	6.00	40	15	6.00	40	16	8.00	50
L16	15	0.00	0	15	1.00	7	16	1.00	6
L17	15	0.00	0	12	0.00	0	16	0.00	0
L18	15	0.00	0	15	0.00	0	16	1.00	0
L19	15	0.00	0	15	1.00	7	16	7.00	44
L20	15	0.00	0	15	1.00	7	16	0.00	0
L21							1	0.00	0
L22	No surveys						7	0.00	0

Survey 1 (29 December 2022 – 12 January 2023)

54. In survey 1, long-tailed bats were recorded by six of the 20 deployed ABMs. Three ABMs within the Wind Farm Site detected bats (L11, L14 and L15). These three ABMs were located along the eastern edge of the Matariki Forest where it abuts the Catlin Conservation Park. Bat activity at L11 and L15 was relatively low with an average of 1.9 bat passes per night. However, L14 showed comparatively very high levels of bat activity with a mean of 46.4 bat passes per night.

55. The other three ABM locations that recorded bat activity (L5, L8, L10) were located to the east of the Wind Farm Site (and to the east of the escarpment) within the Catlins Conservation Park. The Catlins Conservation Park contains beech forest – the likely preferred roosting habitat of long-tailed bats during the breeding season in Southland (Sedgeley and O'Donnell, 1999).

Survey 2 (30 January – 14 February 2023)

56. In survey 2, long-tailed bats were recorded by 13 of the 20 deployed ABMs. L5 had a corrupt SD card and no data was obtained from this ABM.

57. Results again indicated relatively low bat activity. Nine of the 14 on-site ABMs detected bats, with L14 again having comparatively high bat activity with an average of 20.6 bat passes per night. L11 and L15 also recorded more than 1 bat pass per night on average (2.4 and 1.4 respectively). The other six ABMs on-site all recorded on average well below 1 bat pass per night.

58. The five off-site ABMs recorded comparatively low levels of bat activity, ie <0.5 bat passes per night (L1 – L4) and or no bats (L10).

Survey 3 (7 – 23 March 2023)

59. In March the poorer weather conditions including a major storm, caused a reduction in the ABM recording capacity. 15 ABMs recorded long-tailed bat activity across and adjacent to the Wind Farm Site (L3).

60. L3, L7, L12, L15 and L19 recorded on average >1 bat pass per night, with L14 again showing comparatively higher levels of activity with an average of 16.88 bat passes per night. The remaining nine ABMs that recorded long-tailed bat activity, had less than an average of one bat passes per night.

Winter survey 2023 (16 June 2023 – 24 August 2023)

61. The data from survey 4 is provided in **Table 4** below.

Table 4: Nights long-tailed bats were detected at each ABM location during survey 4

MW = 'Matariki Winter'

Logger	Calls	Nights in field	Calls per night
MW1	2	14	0.14
MW10	14	55	0.25
MW11	71	55	1.29
MW14	100	55	1.82
MW15	49	55	0.89
MW2	30	55	0.55
MW3	237	55	4.31
MW6	34	55	0.62
MW4	0	14	0.00
MW5	0	55	0.00

Logger	Calls	Nights in field	Calls per night
MW7	0	14	0.00
MW8	0	55	0.00
MW9	0	14	0.00
MW16	0	55	0.00
MW17	0	55	0.00
MW12	0	14	0.00
MW13	0	14	0.00

62. Eight of the 17 ABMs detected bats. Of these:

(a) MW3, a new site along the escarpment, detected calls as high as the summer surveys (an average of 4.31 calls per night);

(b) MW14 and MW11 consistently detected bats (an average of 1.82 and 1.29 calls per night respectively); and

(c) MW1, MW2, MW6, MW10 and MW15 recorded very few calls (an average of <1 bat call per night).

63. The other nine ABMs detected no calls. MW7 and MW13 were the ABMs deployed off the Site – within the Catlins Conservation Park over 20 km to the southeast of the Southland Wind Farm Site. No bats were detected by these ABMs over a 14 day period.

More extensive bioacoustic surveys 2023/2024

64. The presence of bats on the Wind Farm Site was reconfirmed during all surveys from October 2023 to April 2024. There was both spatial and temporal variation between ABM locations as the surveys progressed. Overall, the results followed patterns observed in 2023, where bat detection levels continued to be very low (for example, as compared to similar surveys at Catlins), and focussed on the Matariki plantation forest property, especially along the edge of the escarpment where the Matariki plantation forest property joins the Slopedown Escarpment (part of Catlins Conservation Park).

65. Surveys 5 – 8 enabled us to meticulously compile a comprehensive dataset of bat activity across the site and to gain a greater understanding of the factors that influence bat activity in that area. A summary of ABM data from surveys 5 – 8 is provided in **Table 5** below.

66. Table 5 shows thousands of hours of effective survey time, with the cumulative number of survey nights from November 2023 to April 2024 being 4,940 recorder nights of survey.

67. A mapped summary of total bat passes at ABM locations for surveys 5 – 8 is shown in Figure Long-tailed Bats-5 (Part G).

Table 5: Summary of raw bioacoustic data for surveys 5 – 8[9]

New Label	Original Label	Wind farm area	Habitat	Total nights of monitoring	Total Bat Passes	Total BP per Night	Total Survey Hours (sunrise to sunset)	Total Hours of Bat Activity	Bat Active Hours (as % of Time)	Nights with bat passes	Max bat passes per night
B01	L68	Glencoe	Forest edge	58	1	0.02	666	1	0.15%	1	1
B02	L67	Glencoe	Paddock	58	1	0.02	666	1	0.15%	1	1
B03	L14	Jedburgh	Forest edge	60	1	0.02	688	1	0.15%	1	1
B04	L21	Glencoe	Paddock	59	0	-	677	0	-	-	-
B05	L22	Glencoe	Manuka edge	59	0	-	677	0	-	-	-
B06	L13	Jedburgh	Manuka/Paddock edge	60	0	-	688	0	-	-	-
B07	L11	Jedburgh	Paddock	62	0	-	706	0	-	-	-
B08	L45	Jedburgh	Paddock	58	0	-	666	0	-	-	-
B09	L12	Jedburgh	Manuka/Paddock edge	62	1	0.02	706	1	0.14%	1	1
B10	L46	Jedburgh	Manuka/Paddock edge	58	1	0.02	666	1	0.15%	1	1
B11	L43	Jedburgh	Paddock	59	0	-	677	0	-	-	-
B12	L44	Jedburgh	Bush edge	59	0	-	677	0	-	-	-
B13	L19	Jedburgh	Paddock	60	1	0.02	688	1	0.15%	1	1
B14	L20	Jedburgh	Manuka/Paddock edge	60	0	-	688	0	-	-	-
B15	L23	Jedburgh	Manuka/Paddock edge	59	0	-	677	0	-	-	-
B16	L47	Jedburgh	Paddock	58	0	-	666	0	-	-	-
B17	L24	Jedburgh	Manuka pond	59	1	0.02	677	1	0.15%	1	1
B18	L48	Jedburgh	Manuka/Paddock edge	58	0	-	666	0	-	-	-
B19	L41	Jedburgh	Manuka edge	65	0	-	737	0	-	-	-
B20	L16	Jedburgh	Manuka edge	60	2	0.03	688	2	0.29%	2	1
B21	L02	Jedburgh	Manuka edge	58	0	-	666	0	-	-	-
B22	L42	Jedburgh	Manuka edge	65	0	-	737	0	-	-	-
B23	L01	Jedburgh	Manuka edge	58	0	-	666	0	-	-	-
B24	L15	Jedburgh	Paddock	60	0	-	688	0	-	-	-
B25	L49	Jedburgh	Paddock	58	3	0.05	666	3	0.45%	3	1
B26	L50	Jedburgh	Bush edge	58	0	-	666	0	-	-	-
B27	L03	Jedburgh	Dense Manuka	64	0	-	726	0	-	-	-
B28	L17	Jedburgh	Manuka edge	59	4	0.07	677	3	0.44%	3	2
B29	L18	Jedburgh	Manuka edge	59	3	0.05	677	2	0.30%	2	2
B30	L60	Jedburgh	Manuka edge	65	0	-	737	0	-	-	-
B31	L04	Jedburgh	Manuka edge	64	2	0.03	726	2	0.28%	2	1
B32	L59	Jedburgh	Manuka edge	65	0	-	737	0	-	-	-
B33	L52	Jedburgh	Manuka edge	58	1	0.02	666	1	0.15%	1	1
B34	L51	Jedburgh	Scrub	58	1	0.02	666	1	0.15%	1	1
B35	L57	Jedburgh	Manuka edge	65	5	0.08	737	2	0.27%	2	4
B36	L58	Jedburgh	Manuka edge	65	372	5.72	737	16	2.17%	8	213
B37	L07	Jedburgh	Scattered Manuka	64	0	-	726	0	-	-	-
B38	L26	Jedburgh	Bush edge	58	2	0.03	666	1	0.15%	1	2
B39	L08	Jedburgh	Scattered Manuka	64	0	-	726	0	-	-	-
B40	L06	Jedburgh	Scrub	64	5	0.08	726	2	0.28%	2	3
B41	L56	Jedburgh	Scrub	65	1	0.02	737	1	0.14%	1	1
B42	L55	Jedburgh	Scrub	65	1	0.02	737	1	0.14%	1	1
B43	L05	Jedburgh	Manuka edge	64	4	0.06	726	2	0.28%	2	2
B44	L25	Jedburgh	Manuka edge	65	0	-	739	0	-	-	-
B45	L09	Jedburgh	Scattered Manuka	64	5	0.08	726	4	0.55%	3	2
B46	L53	Jedburgh	Scrub	65	4	0.06	737	3	0.41%	3	2
B47	L10	Jedburgh	Bush edge	64	6	0.09	726	3	0.41%	3	2
B48	L62	Matariki	Manuka edge	62	1	0.02	707	1	0.14%	1	1
B49	L54	Jedburgh	Bush edge	65	3	0.05	737	3	0.41%	2	2
B50	L61	Matariki	Manuka edge	62	1	0.02	707	1	0.14%	1	1
B51	L27	Jedburgh	Dense manuka	65	0	-	739	0	-	-	-
B52	L28	Matariki	Forest edge	66	162	2.45	751	24	3.20%	14	110
B53	L63	Matariki	Forest	62	2	0.03	707	2	0.28%	2	1
B54	L64	Matariki	Forest edge	62	49	0.79	707	23	3.25%	13	15
B55	L33	Matariki	Forest track	66	4	0.06	751	1	0.13%	1	4
B56	L34	Matariki	Forest track	66	1	0.02	751	1	0.13%	1	1
B57	L29	Matariki	Forest edge	66	41	0.62	751	8	1.07%	7	24
B58	L30	Matariki	Forest edge/pond	66	180	2.73	751	38	5.06%	21	45
B59	L38	Matariki	Forest edge	66	2	0.03	751	2	0.27%	2	1
B60	L70	Matariki	Forest edge	63	19	0.30	718	11	1.53%	8	5
B61	L69	Matariki	Forest edge	63	27	0.43	718	10	1.39%	9	13
B62	L32	Matariki	Forest track	66	2	0.03	751	1	0.13%	1	2
B63	L37	Matariki	Forest track	80	256	3.20	905	42	4.64%	21	102
B64	L31	Matariki	Dense Forest	66	106	1.61	751	19	2.53%	14	77
B65	L74	Matariki	Scattered forest	59	1	0.02	678	1	0.15%	1	1
B66	L73	Matariki	Scattered forest	59	2	0.03	678	2	0.29%	2	1
B67	L76	Matariki	Forest track	59	9	0.15	678	1	0.15%	1	9
B68	L75	Matariki	Forest edge	59	1	0.02	678	1	0.15%	1	1
B69	L65	Matariki	Scrub	59	0	-	678	0	-	-	-
B70	L66	Matariki	Forest edge	59	0	-	678	0	-	-	-
B71	L40	Matariki	Scattered forest	62	2	0.03	711	2	0.28%	1	2
B72	L39	Matariki	Forest edge	62	48	0.77	711	19	2.67%	13	17
B73	L71	Matariki	Scrub	59	4	0.07	678	4	0.59%	3	2
B74	L72	Matariki	Scrub	59	33	0.56	678	12	1.77%	7	12
B75	L35	Matariki	Scrub	62	2	0.03	711	2	0.28%	2	1
B76	L79	Matariki	Forest edge	59	0	-	678	0	-	-	-
B77	L36	Matariki	Dense Forest	62	93	1.50	711	28	3.94%	17	46
B78	L80	Matariki	Forest edge	59	11	0.19	678	8	1.18%	6	4
B79	L77	Matariki	Forest edge	59	11	0.19	678	8	1.18%	6	5
B80	L78	Matariki	Forest track	59	7	0.12	678	6	0.88%	4	3

Survey 5 (30 October – 30 November 2023)

68. A total of 131 bat passes were recorded across eight of the 80 ABMs, six of which were located in or near plantation forestry. Overall, the average bat passes per night across the eight ABMs was 0.82:

    (a) Five ABMs along the Mataraki escarpment B58 (L30), B77 (L36), B63 (L37), B54 (L64) and B79 (L77) detected bats. However, the number of detections were much lower compared to previous surveys:

        (i) Three ABMs B58 (L30), B77 (L36) and B63 (L37) recorded over one bat pass per night, with 3.06, 1.06 and 1.55 respectively.

        (ii) The other two ABMs B54 (ML64) and B79 (L77) recorded 0.23 and 0.07 bat passes per night respectively.

    (b) One ABM between the Mataraki escarpment and Jedburgh B52 (L28) recorded 0.35 bat passes per night.

    (c) Two ABMs on Jedburgh Station B38 (L26) and B25 (L49) recorded 0.14 and 0.07 bat passes per night respectively.

69. Aside from the weather being outside of the wind and temperature parameters determined to be ideal for acoustic surveys during some of the November round of surveys, low numbers could also be because bats generally focus their flying areas around their core breeding areas due to being pregnant and about to give birth at this time the year.

Survey 6 (3 – 24 January 2024)

70. A total of 69 bat passes were recorded across 14 of the 80 ABMs, ten of which were located in or near plantation forestry. Overall, the average bat passes across the 14 ABMs per night was 0.27. Only one ABM B36 (L58), which was located in the Matariki conifer plantation forest, had over one bat pass per night.

Survey 7 (20 February – 7 March 2024)

71. Survey 7 saw an increase in long-tailed bat activity across the site with 751 bat passes recorded across a total of 45 of the 80 ABMs. Of the 45 ABMs

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[9] The 'New Label' column has been provided with numbering west to east to assist in locating the ABMs across the Wind Farm Site on maps and in the analysis results.

that recorded bat activity, 23 were located in Matariki Forest and 22 were located in a range of habitats on Jedburgh Station and Glencoe Station.

72. Overall average bat passes per night for the ABMs was 1.46 at Matariki Forest and 0.61 at Jedburgh Station and Glencoe Station. However, the majority of bat passes recorded on Jedburgh Station and Glencoe Station were recorded at just one ABM B36 (L58).

Survey 8 (3 – 17 April 2024)

73. Survey 8 saw a slightly lower level of long-tailed bat activity across the Wind Farm Site than during survey 7, with 557 bat passes recorded across a total of 21 of the 80 ABMs. Of the 21 ABMs that recorded bat activity, six were located in Jedburgh/Glencoe Stations and 15 were located in Matariki Forest.

74. Overall average bat passes per night for the ABMs was 1.54 at Matariki Forest and 2.77 at Jedburgh Station and Glencoe Station. However, the majority of bat passes at Jedburgh were recorded at just one ABM B36 (L58) – the same ABM that recorded the majority of bat passes during survey 7.

Meteorological Mast bioacoustics survey results

75. The MAST ABM at 80m height was deployed between 21 November 2023 and 22 January 2024, again between 19 February 2024 and 25 March 2024 and also between 9 April 2024 and 7 May 2024. No bats were detected at the ABM located at the top of the 80m tall meteorological mast during any of the recording sessions. ABMs B48 (located 170m west from the base of mast) and B50 (located 50m southwest from the base of the mast) recorded just one long-tailed bat pass each during the 2023-2024 surveys. B48 recorded its bat pass in survey 6 on 20 January 2024, and B50 recorded its bat pass on 1 March 2024 in survey 7.

76. It is clear from the wider monitoring study that the location of the meteorological mast is not now predicted to be an area that long-tailed bats would visit on a regular basis due to its general location and habitat type (low scrub and manuka vegetation). The results are therefore helpful in indicating bats do not fly at such heights in this location, that bats did not appear to investigate the full height of the mast and did not appear to be attracted to the safety aviation lighting at the top of the mast. However, it is not possible to use those results to account for the behaviour of bats in other locations (particularly where bat activity at ground level was greater) due to the very low sample size.

77. During the Covid Fast-track consenting process, there was agreement between the bat experts that there are significant practical challenges associated with undertaking a well-designed bioacoustic survey at height. It is assumed, on a conservative basis, that long-tailed bats are at risk of colliding with turbines at height.[10]

Radio tracking surveys

78. The locations of trapping sites are shown in Figure Long-tailed Bats-11 (Part G).

Radio tracking survey 1

79. On 21 February 2024 15 long-tailed bats were captured, including 12 female bats (five of which were post lactating), one male adult and two male juveniles. Four female bats comprising of two post lactating (Tx2 and Tx4) and two non-breeding bats (Tx1 and Tx3) were tagged with transmitters.

80. On 22 February 2024 using the same trap locations in similar weather conditions, no bats were captured.

81. On 26 February 2024 a male adult long-tailed bat was captured on the Catlins Road (see T7) and not tagged.

82. On 27 February 2024 one male adult and a male juvenile were captured at T1 and both were tagged (Tx5 and Tx33).

83. **Table 6** below shows the summary data of the tagged bats and their respective roosting locations. Roost locations are shown in Figure Long-tailed Bats-12 (Part G).

Table 6: Summary of Catlins River area roosts (February 2024)

Roost Ref	Date found	Bat refs (Tx) use	Type	Roost Feature	Count of bats
RC01	22/02/2024	03, 04	Silver beech	Knothole	8
RC02	23/02/2024	01, 03	Silver beech	Unknown	Not seen emerging
RC03	24/02/2024	03	Silver beech	Unknown	3
RC04	25/02/2024	03	Silver beech	Dead wood	9
RC05	27/02/2024	03	Silver beech	Knothole on dead limb	19
RC06	29/02/2024	33	Dead tree	Unknown	No Emergence

[10] FTC-SWF-expert-conferencing-JWS-ecology-bats.pdf at [22].

84. A total of six roosts were located in the Catlins River valley (5 roosts) and Beresford Ranges (1 male roost). These existing long-tailed bat populations are likely part of known populations present approximately 10-20 km to the southeast of the Southland Wind Farm site in the Catlins Forest Park, mainly centred in the Tahakopa Valley and the Catlins and Thisbe Rivers. Tx2 (post lactating female) and Tx5 (male adult) were not located, indicating additional roosts that were not found. Roosts RC01 – RC05 are considered long-tailed bat maternity roosts (though noting that in late February, with bats dispersing and mixing with male bats (mating period) such roosts are less likely to be tightly defined).

Radio tracking survey 2

85. A total of six roosts were located in the Slopedown Escarpment via trapping. **Table 7** below shows the summary data of the tagged bats and their respective roosting locations. Roost locations are shown in Figure Long-tailed Bats-12 (Part G).

Table 7: Summary of Southland Wind Farm area roosts (March 2024)

Roost Ref	Date found	Bat refs (Tx) use	Vegetation Type	Roost Feature	Count of bats
RM01	21/03/2024	TxM01	Southern rata	Dead wood/knothole	No emergence
RM02	22/03/2024	TxM01	Dead southern rata	Unknown	No emergence
RM03	23/03/2024	TxM01	Southern rata	Unknown	No emergence
RM04	24/03/2024	TxM01	Kanuka	Unknown	No emergence
RM05	25/03/2024	TxM01	Southern rata	Unknown	No emergence
RM06	25/03/2024	TxM02	Podocarp Forest	Unknown	No emergence

86. On 20 March 2024 two long-tailed bats were captured (no bats captured on 19 March 2024), including a mating male (TxM01), which was determined from examination of genitalia including the presence of enlarged testes, and a female juvenile (TxM2). Both bats were fitted with radio transmitters. Five roosts were from the male mating bat TxM01. This bat moved daily to a new tree, but within the same area. Roosts RM01 – RM05 are considered long-tailed bat mating roosts, due to the breeding condition of this male bat (see Figure Long-tailed Bats-12 (Part G)). Little is known about mating strategies of long-tailed bats, although similar species overseas often operate a hareem

system, where males advertise their roosts (using social calls) and attract passing females.

87. Although emergence surveys of the roost trees RM01 – RM05 were not possible due to safety considerations, a vantage point survey overlooking the roosting area was undertaken each night. This recorded the time of emergence of bat TxM01 (invariably between 20 and 30 minutes after sunset) and followed the bat's activity for two-three hours. TxM01 generally flew within approximately 500 m from its roost during this time, but would also make 1-2 bouts over the escarpment to the north and was recorded flying within the creek valley east of Trap site TM4 for around 30 minutes (see Figure Long-tailed Bats-12 (Part G)).

88. Female juvenile bat TxM02 was rarely heard during the post emergence surveys. Her roost was located by helicopter on 27 March 2024, but due to weather conditions and resource limitations, no emergence survey was undertaken. The only other observation of this bat was made on 21 March 2024 following TxM01 emergence, when she was observed flying below the escarpment from the south west towards TxM01's roosting area, before flying over the escarpment northwards to the creek valley east of TM4. Its signal was lost south west of the escarpment after spending approximately 40 minutes flying in the creek valley.

Interpretation of results

B63 (L14 in surveys 1 – 4) as an outlier

89. During the first set of surveys (1 – 4) L14 was considered an outlier in terms of data. It was situated along a forestry road, bounded on both sides by tall pine forest, in a sheltered location near a stream which is ideal bat foraging and commuting habitat and thus not considered representative of the high, exposed locations of the turbine locations within the Site.

90. In survey 5 an ABM B63 was located in the same location as L14 for the previous surveys 1 – 4 and another ABM, B59, was located close to proposed turbine Mat-06, the closest turbine to this area of high bat activity. These two ABMs recorded concurrently over a two week period. ABM B63 recorded 48 bat passes, while no bat calls were detected at ABM B59, despite it being only 245 m from B63 (see Figure Long-tailed Bats-6 (Part G)). A key difference between these two locations is that B63 is adjacent to a forestry road within a mature/tall stand of trees and also at a lower elevation

than site B59 – which is on a hill to the west of B63. These two aspects provide shelter at site B63 from the predominant wind direction (west-northwest). Furthermore, a stream runs through a gully immediately to the east of B63, providing good habitat for flying insect life – and thus a source of food for bats.

Statistical analysis undertaken for surveys 5 – 8

91. **Figures 1 – 3** below show a simple correlation of bat activity with calls per hour, frequency of calls against wind speed and frequency of hours where bat calls were detected, to illustrate key overriding activity patterns.

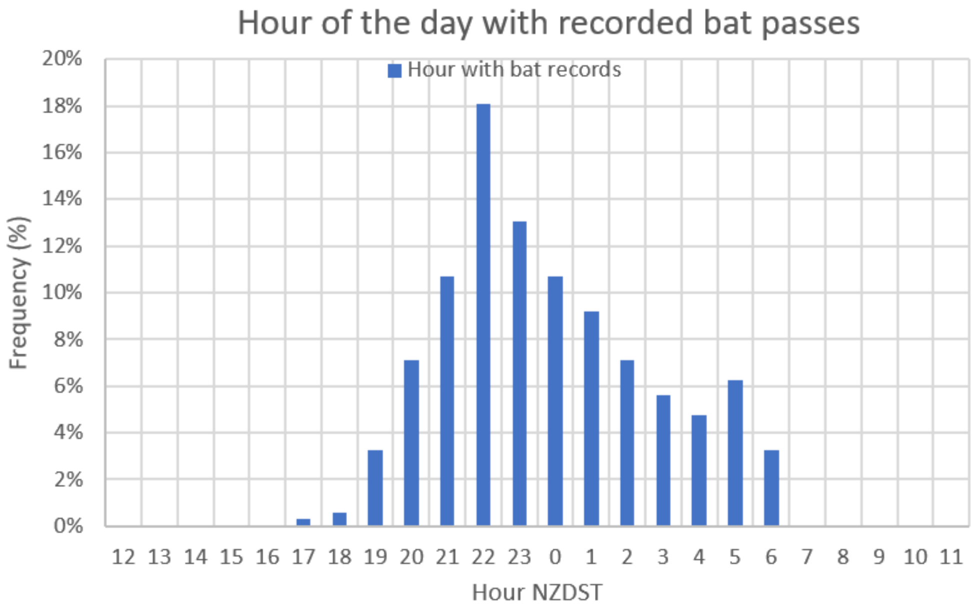

Figure 1: Frequency (expressed as %) of hours where long-tailed bat calls were detected over hours from dusk until dawn for surveys 5 – 8

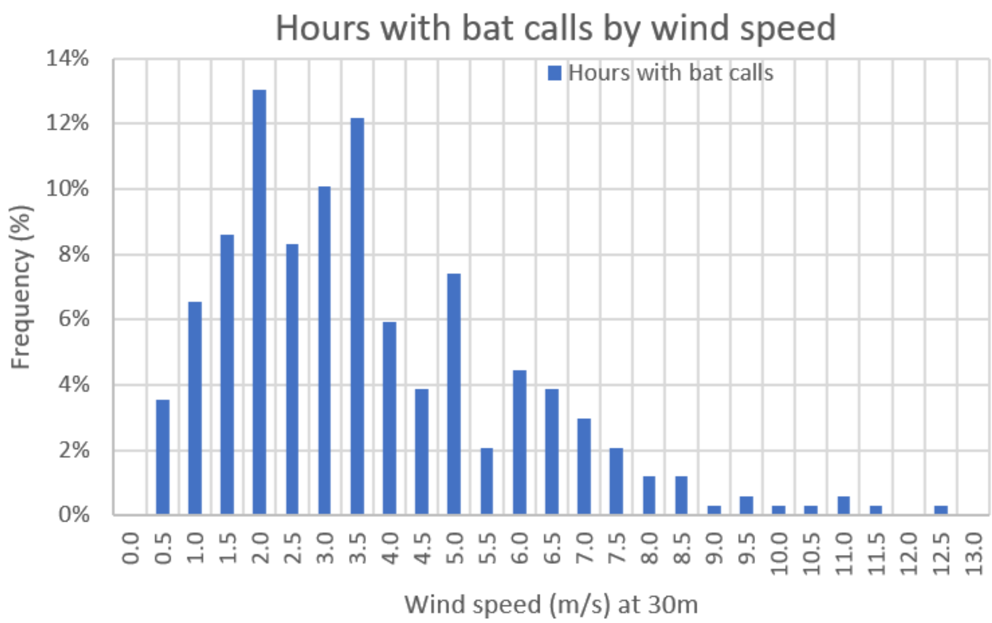

Figure 2: Frequency (expressed as %) of hours where long-tailed bat calls were detected over surveys 5 – 8 against recorded wind speed at 30 m above ground at the proposed Wind Farm Site

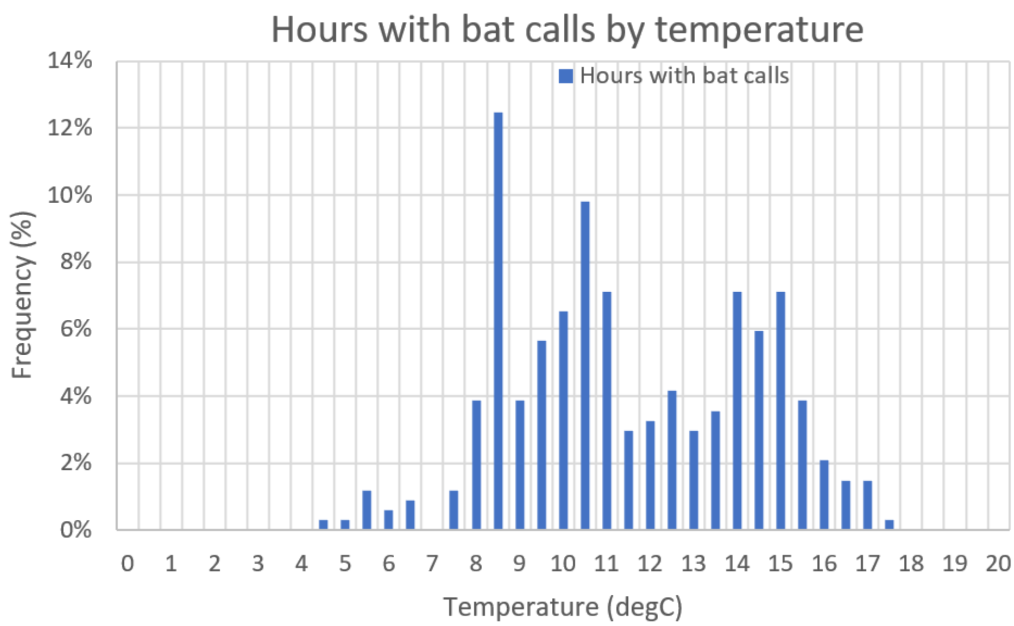

Figure 3: Frequency (expressed as %) of hours where long-tailed bat calls were detected over surveys 5 – 8 against recorded ambient temperature at the proposed Wind Farm Site

92. All six statistical models used by Proteus reported similar overall trends to Figures 1 – 3 above. Generally, bat activity (counts or presence) had a negative relationship with wind speed, distance to the nearest track, and distance to the nearest river, indicating that bat activity tended to be higher during periods of low wind speeds and in proximity to tracks and rivers.

93. Moreover, bat activity had a positive relationship with maximum vegetation height, suggesting higher activity at locations with tall vegetation nearby and

(more weakly) at higher elevations. All three Tweedie models show a positive relationship between bat call counts and vegetation height where counts increased by 9.42 – 14.11% for every metre increase in vegetation height.

94. All models indicated a strong seasonal effect, with more bat activity recorded during surveys 7 and 8 (March and April).

95. The hourly binomial and hourly Tweedie models also included wind direction, time of night, and temperature as covariates. Both models indicated that bat activity increased with rising temperatures, decreased as the night progressed, and was positively associated with easterly and northerly winds, likely associated with raising temperatures from these wind directions. For example, the hourly Tweedie model highlighted a 29.17% increase in bat counts per degree increase in temperature.

96. All models highlighted that sampling sessions three and four, which took place in March and April, respectively, had significantly more bat activity than sessions earlier in the season. As a result, the risk of bat mortalities may be higher while wind turbines are operational during these months.

97. In terms of a collection of bat activity and wind speed, all models highlighted a negative relationship between the number of bat calls and wind speed, where detection decreased by 8.15 – 42.88% for each metre per second increase in wind speed depending on the model that was run.

98. Bat activity was estimated to peak approximately 5 – 6 hours after sunset, and then decline as the night progressed.

99. Lastly the presence of rain had a strong negative effect with a 61.75% decrease in bat activity when rain was recorded during the hour.

100. **Figure 4** below (Figure 4.23 of the Proteus report) provides a plot graph illustrating the relative strength of the association between key environmental variables and bat activity. For example, surveys 7 and 8 between mid-February and mid-April (termed 'Period 3' and 'Period 4' in the plot graph), have a strong association with increased bat activity, while survey 6 during January (Period 2) has a weak correlation with bat activity.

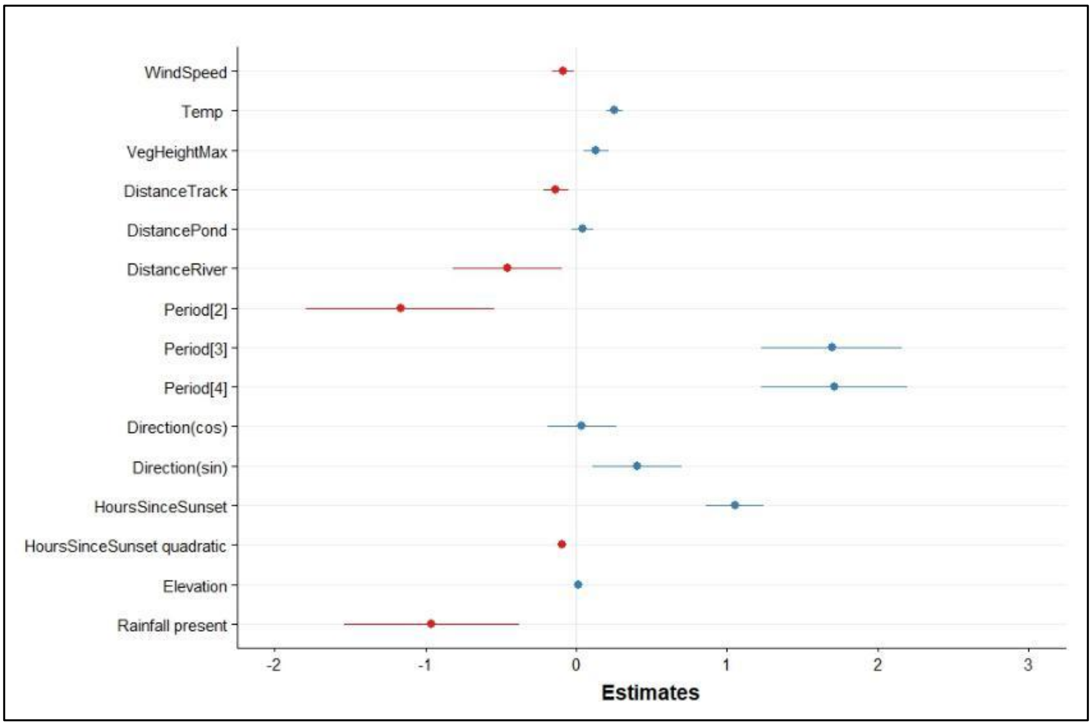

Figure 4: Plots of the coefficients for the predictor variables in the models for total number of bat call detection per hour at each ABM logger for surveys 6 – 8. Positive coefficients (blue) indicate a positive association with the response variable, while negative coefficients (red) indicate a negative association. The horizontal error bars represent 95% confidence intervals

101. While wind speed is only weakly correlated with decreasing bat activity in the plot compared to variables such as seasonality and distance to water ways, detection rates still decreased by 8.15 – 42.88% for each metre per second increase in wind speed, which is statistically significant.

102. Based on the consistent results across these multiple models, it is evident that there are several variables which should be considered when determining the parameters for a set curtailment regime. Specifically:

(a) March and April showed the highest level of activity of the months surveyed;

(b) tall vegetation is associated with a higher level of bat activity across all models;

(c) bat activity is predicted to be higher in areas that are close to rivers and tracks;

(d) bat activity declines as wind speed increases;

(e) bat activity increases with temperature increases; and

(f) bat activity decreases with rainfall.

103. This analysis has informed the parameters we have recommended for a set curtailment regime.

Radio tracking results

104. Despite the challenges of trapping bats that use the Wind Farm Site at the end of the bats' active season, the trapping and tracking has provided valuable insights. The radio tracking data suggests that small populations of bats (such as male mating bats) are roosting in the Slopedown Escarpment and are making frequent visits to the exotic plantations to areas in and around the escarpment within the Wind Farm Site, but are not found to be roosting there. The sample size of radio tracked bats is small, but these data provide a highly persuasive addition to the overall interpretation of the ABM data, especially as the radio tracked bats were captured in the area of one of the ABMs that consistently detected bats in all bioacoustic surveys i.e. being one of the most active areas for bats on the Wind Farm Site.

105. The radio tracking surveys have identified a suitable area in the Catlins Conservation Park (Catlins River) that would benefit from direct pest control to help protect a maternity population. This site could be used as the core part of a compensation package to address residual effects on long-tailed bats. To confirm, this area is within the 10,000ha area that is covered by Contact's compensation proposal, discussed further below.

ASSESSMENT OF EFFECTS

Summary of effects

106. Wind farms can affect non-migratory, tree roosting, insectivorous micro-bats in the following ways:

    (a) fragmentation of roosting, commuting and foraging habitat, (wind farms may form barriers to commuting or seasonal movements, and can result in severance of foraging habitat); and

    (b) displacement of individuals or populations (due to wind farm construction or because bats avoid the wind farm area); and

    (c) direct collision mortality or injury, barotrauma and other injuries;

107. A literature review of international and New Zealand evidence of these effects is provided in **Appendix Two**.

108. We consider the unmitigated level of effect of habitat removal and habitat displacement from the Project to be Low. Following the implementation of the effects management measures proposed, the effect of habitat removal and habitat displacement will be negligible.

109. The unmitigated effect of turbine strike from the Project varies across the Wind Farm Site. The un-mitigated effect of turbine strike risk is:

(a) Low in areas of Low habitat value (ie Jedburgh Station and Glencoe Station); and

(b) Moderate in areas of Moderate habitat value (ie the northern and western portions of Matariki Forest); and

(c) Very High in areas of High and Very High habitat value (ie the eastern part of Matariki Forest, adjacent to the escarpment).

110. Following the implementation of the curtailment regime/strategy proposed, the effect of turbine strike will be low at most.

Habitat removal

111. Habitat loss occurs when a portion of the long-tailed bat's natural habitat is removed or altered due to the construction of wind turbines and associated infrastructure. Habitat removal during construction of the wind farm infrastructure may cause significant adverse effects if not addressed by a range of suitable avoidance, remediation and mitigation measures. In the case of the Project the footprint of the turbine platforms, access roads and other associated infrastructure are likely to be of such a relatively small size that the loss of this relatively low quality habitat in the context of similar pastoral habitats will be insignificant.

112. Long-tailed bats are cavity roosting bats. Roost trees are both in large trees within indigenous vegetation and in non-native trees such as pine, macrocarpa, elm, wattle, popular, and eucalypt (Daniel 1981, O'Donnell and Sedgeley 1999, Pryde et al. 2005, Griffiths 2007).

113. Removal of trees with cavity bearing features could remove potential bat roost trees, and possibly result in harm to long-tailed bats occupying those trees. The results of the radio tracking surveys indicate that long-tailed bats are roosting in native forest adjacent to the Wind Farm Site, but there is no evidence to suggest they are roosting within the Wind Farm Site and further,

the low levels of bat activity recorded across the Wind Farm Site also support this. Thus, there is no evidence that roosting is common place, if at all within the Wind Farm Site. Given this, application of current best practice protocols[11] to check for potential occupied roots can be targeted to old growth stands only, which are not currently within the plantation rotation cycle, such as old/mature stands of exotic trees near Mat-01, Mat-16/Mat 17, Mat-07 and Mat-12. In the unlikely scenario that an occupied bat roost tree is found within the Project footprint, these protocols provide direction on the appropriate steps to avoid harming individual bats and mitigation measures for addressing the loss of a roost tree. The details of these measures and where they are to be applied should be included in the Bat Management Plan.

Habitat displacement

114. Habitat displacement happens when long-tailed bats are less likely to use all of their original habitat due to the presence of an operational wind farm. The construction and operation of wind turbines can create disturbances such as noise, vibrations, and changes in air pressure that can disrupt the bats' normal behaviours and routines.

115. The analysis that we undertook shows that approximately 303 ha of vegetation and other non-vegetated areas (including existing roads) would be removed or displaced by the construction of the 55 turbines of the Southland Wind Farm. This includes 161.63 ha removed or altered by road and infrastructure associated construction and another 82.48 ha associated with the aggregate of the rotor swept area of the 55 turbines (assuming all of the rotor swept area is 'lost' as habitat for bats) and 5.15 ha associated with the construction of the transmission line. There is another 53.43 ha of vegetation under the transmission line which may require trimming; in effect creating low-stature habitat for bats, which may be of less value than high-stature vegetation to bats. This area has been broken down by vegetation type, as set out in **Table 8** below. An example of the mapped vegetation layer, with combined rotor zone and vegetation clearance area combined and clipped to the vegetation layer, is provided in Figure Long-tailed Bats-13 (Part G).

[11] Department of Conservation: Protocols for Minimising the Risk of Felling Occupied Bat Roosts (Bat Roost Protocols), Version 4: October 2024). 4 approved by the New Zealand Department of Conservation’s Bat Recovery Group

Table 8: Area of vegetation types and roads (as per Wildland 2023) removed, altered or displaced by the Southland Wind Farm footprint and rotor swept zone

Vegetation Name	Area (Ha) Civil Works Wind Farm	Area (Ha) Civil Works Tx Line	Area (Ha) Rotor Swept Area (170m Diameter)	Area (Ha) Tx Line
[Gorse]/copper tussock grassland	0.21	-	0.00	-
[Mānuka]/gorse-tauhinu scrub	0.55	0.08	1.68	-
[Mānuka]/tauhinu-inaka-Vernonica odora scrub and shrubland	24.77	0.45	11.63	-
[Mānuka-gorse]/copper tussock grassland	0.56	-	0.67	-
[Wilding conifers]/copper tussock grassland	0.02	-	-	-
[Wilding conifers]/copper tussock shrubland	1.36	-	0.90	-
[Wilding conifers]/gorse-copper tussock scrub	0.01	-	-	-
Bog wetland	0.94	-	2.46	-
Copper tussock grassland	0.23	-	0.06	-
Copper tussock/rautahi marsh	0.01	-	0.03	2.57
Exotic conifer plantation forest	23.04	2.26	11.73	33.14
Exotic grazed grassland	34.13	1.18	10.95	12.77
Exotic un-grazed grassland	0.26	0.21	-	2.17
Exotic unmanaged grassland	12.81	0.06	6.77	-
Fen wetland	1.06	0.02	3.45	-
Gorse scrub	6.68	0.09	5.17	-
Gorse/copper tussock grassland	2.44	-	1.35	-
Gorse/copper tussock shrubland	2.75	-	1.03	-
Inaka scrub	0.96	-	0.49	-
Indigenous broadleaved forest and scrub	-	-	-	0.83
Indigenous scrub and shrubland	0.45	-	-	0.02
Kohuhu/gorse/rarauhe scrub	0.00	-	-	-
Mānuka forest and scrub	16.44	0.42	13.08	-
Mānuka scrub	0.71	-	1.81	-
Mānuka scrub/shrubland	1.61	-	1.33	0.16
Mānuka/copper tussock grassland	2.86	-	0.99	-
Mānuka-gorse/copper tussock shrubland	3.46	-	2.28	-
Mānuka-haumakaroa-mountain holly forest	1.03	0.04	0.33	-
Mānuka-inaka/copper tussock marsh	-	-	0.23	-
Mānuka-inaka-mountain holly-(gorse) scrub and shrubland	3.44	0.21	1.27	-
Mixed indigenous-conifer forest and scrub	0.37	0.07	-	0.34
Riparian vegetation	0.29	-	-	1.03
Road	16.80	0.06	0.69	0.40
Southern rātā-kamahi forest	0.74	-	1.57	-
Wilding conifers/mānuka-copper tussock shrubland	0.63	-	0.54	-
	161.63	**5.15**	**82.48**	**53.43**

116. The effects of this habitat displacement are considered minor given the low bat activity rates across the Wind Farm Site from the bioacoustic surveys, and the similar or higher quality habitat available to this population of long-tailed bats. The loss of vegetation is, in general terrestrial ecological terms, assessed in the Terrestrial and Wetland Ecology Report, with measures to

address those effects proposed. However, we have recommended that the residual effects of this habitat displacement on bats be specifically assessed, and addressed, through the proposed compensation. This compensation package addresses residual effects of the wind farm on bats, including habitat displacement effects[12] (we discuss the proposed compensation later in this report).

Strike-risk

117. Based on the international literature, we considered it probable that long-tailed bats are at risk of wind turbine strike and/or barotrauma injury and mortality at the proposed Southland Wind Farm due to:

(a) the more open, as well as edge forest habitats that long-tailed bats use;

(b) the presence of these habitats within the vicinity of several of the proposed turbine locations; and

(c) the behavioural characteristics of long-tailed bats being similar to overseas species which have been proven to be at risk through scientifically robust carcass search studies at operational wind farms.

Determination of strike risk – the Bat Risk Area

118. Figure Long-tailed Bats-7 (Part G) and Figure Long-tailed Bats-8 (Part G) illustrate the areas of highest long-tailed bat activity across the bioacoustic surveys.

119. Given the limitations of using one metric to identify bat activity, following the extensive bioacoustic surveys we created four bat activity indices (**BAI**). The BAI express a range of activity metrics over the site to smooth out the outlier data. We used these BAI to refine the data such that we could identify the level of risk of bat strike across the Wind Farm Site. Our full methodology for this exercise is described in **Appendix One**.

120. Based on the BAI scores (set out in **Table 10** in **Appendix One**), a review of the predictive modelling and a more fine-grained review of the dataset and specific physical characteristics of each turbine site, we consider:

(a) that the risk of bat strike is likely to be Very Low to Low across Jedburgh Station, Glencoe Station and the northern part of Matariki

[12] See para 19 second JWS of experts in the field of Ecology – bats – dated 19 October 2024 for Covid Farsk Track application

Forest, because of the very low levels of bat activity found in these localities;

(b) that the level of bat activity is generally higher in the southern part of Matariki Forest, adjacent to the escarpment in an area identified as the Bat Risk Area; and

(c) within the Bat Risk Area most turbines pose a Moderate bat strike risk and as a consequence, and based on the specific site risk parameters and the bat activity data, turbines sites MAT-01, MAT-02, MAT-03, MAT-04, MAT-06, MAT-07, MAT-12, MAT-16 and MAT-17 should have their operation curtailed during certain conditions to minimise the potential effects on bats.

121. Figure Long-tailed Bats-9 (Part G) illustrates the BAI weighted score and Figure Long-tailed Bats-10 (Part G) illustrates the turbines within the Bat Risk Area where specific mitigation is required to minimise effects on bats.

122. We make a few further comments in respect of **Table 10** and the Bat Risk Area in **Appendix One**.

123. The BAI of the data logger activity at MAT-17 displays characteristics of higher regular use, but the vegetation is relatively young at present to moderate this higher use pattern. During the previous Covid Fast-track process for the Project, Contact agreed that MAT-17 would be subject to curtailment from the outset.

124. While turbines MAT-14 and MAT-15 are geographically within the Bat Risk Area, they are considered to be very low risk turbines for potential turbine blade strike. This is because both turbines are situated in elevated and exposed sites where the vegetation surrounding them consists of short manuka-gorse/copper tussock grassland and shrubland. The Wildlands vegetation mapping indicates there is no tall exotic vegetation within at least a 200 m radius of either turbine. In addition, the two nearest loggers to MAT-15 have a sum weighted index (BAI) score less than 1, thus representing a locality of very low risk of potential turbine strike for long-tailed bats (i.e. Logger B74 has a weighted score of 0.9 and Logger B73 has a weighted score of 0.0). For these reasons, specific mitigation measures are not required for these turbines.

125. There are three other turbine sites where the predictive modelling and the BAI analysis show higher levels of activity, but for which we consider no

specific strike risk management intervention is required.[13] These are JED-14; JED-31 and MAT-08:

(a) Turbine JED-14: the ABM deployed at the same location of this turbine (IB35) had only five bat passes over two nights through all the survey sessions (one night in February and one night in April). The next nearest ABM (B36) is located approximately 125 m away and had 372 calls over nine nights in March and April. However, this was considered likely to be ad hoc foraging event as no other ABM in low manuka (<5 m in height) scrub (similar habitat) had any activity results resembling this site, either in the 2023-2024 surveys season or in the 2022-2023 season. Given the low vegetation height (which is already below 5 m) and very low bat activity at JED14, as well as the consistently low bat activity associated with Manuka habitat/low vegetation height, it would be disproportionate to apply curtailment to JED-14. Any residual risks (accepting there will be ad hoc bat activity across the site from time to time) is adequately addressed through compensation.

(b) Turbine JED-31: the ABM deployed at the same location of this turbine (B51) had no bat passes recorded at the turbine location itself. The next nearest ABM (B52) located approximately 200 m away, had 167 passes over three survey sessions, November, March and April. However, this ABM is located next to a track and within exotic plantation with taller vegetation height, which the modelling shows are both significant predictors of bat activity. For wider context, there was also very little bat activity at the next nearest ABMs (approximately 400 m to the northwest) in similar habitats with only one call recorded on each ABM (B50 and B48) throughout the 2023-24 season. Given the low vegetation height (which is already below 5 m), and that there was no bat activity at the turbine, and the consistently low bat activity associated with manuka habitat/low vegetation height generally, it would be disproportionate to apply curtailment to JED-31. Any residual risks (accepting there will be ad hoc bat activity across the site from time to time) would be addressed through compensation.

(c) Turbine MAT-08: located within the exotic plantation and near a track, the ABM results for this turbine site show bat activity was very low, with just one bat pass during 2023-2024 survey (logger B62). The next

[13] This was agreed by all experts involved in the previous Covid Act consenting process.

nearest ABM (logger B64), located approximately 100 m away, had 106 passes over three 2024 survey sessions, January, February/March and April. However, when analysing the wind data for this site specifically, all bat activity was when the wind speed was below 2m/s (at 30 m height) suggesting that bats are not active here in higher wind speeds when the turbines would likely be operating and therefore curtailment mitigation would not be necessary to reduce risk. The location of this ABM is also at the northerly limit of bat activity from the escarpment where radio tracking has identified known and likely roosting sites, and therefore it is considered the northern part of Matariki Forest and within the lower risk bat zone which is more appropriately addressed through compensation.

Transmission line

126. Based on the literature review it is considered that the effect of the construction and operation of the transmission line as part of the Project on long-tailed bats is likely to be Low to Negligible.

MEASURES TO REMEDY OR MITIGATE ACTUAL OR POTENTIAL ADVERSE EFFECTS

127. As set out above in the effects assessment, it is important to note that the Wind Farm Site is not a high use area, and is unlikely to be critical, core foraging habitat for the local bat population. Nor have bats been observed to roost on the Wind Farm Site (though we accept it is possible that they could).

128. The predominant vegetation attracting the bats consists of mature exotic pine trees, which are part of a commercial forestry operation. Due to the ongoing commercial activities, this vegetation is likely to be altered or removed at some point in the future, irrespective of the wind farm development, and therefore, it will not be maintained or protected as bat habitat in the long term.

129. Having adopted a conservative approach to the assessment of effects and interpretation of the comprehensive data, we recommend the following measures:

(a) vegetation clearance protocols (checking for bats / roosts prior to vegetation clearance) in potential roost trees within old/mature stands of exotic trees near MAT-01, MAT-16/MAT-17, MAT-07 and MAT-12;

(b) trialling live curtailment for an initial operational period for the identified nine turbines in the Bat Risk Area;

(c) compensation for residual effects via an animal pest control programme within a 10,000 ha intensive control area (**ICA**) in the Beresford Range, (a measure jointly identified and agreed with DOC); and

(d) post-commissioning bat monitoring requirements.

130. These measures are set out in Contact's proposed conditions, and as discussed previously, the measures (and conditions) were agreed by the bat experts to be appropriate in the Covid Fast-track consenting process. We note that it was previously agreed that set and live curtailment would be trialled together, but for practical reasons, we now propose to trial live curtailment on its own, as it is our view that this will be more effective in demonstrating its efficacy. This updated approach has been discussed with DOC.

131. The details in terms of implementing these measures will be set out in a Bat Management Plan, to be developed and certified after the consenting process. Again, the bat experts have previously agreed that this is appropriate. A draft version of the Bat Management Plan has been submitted with this application.

132. We also recommend that an expert bat panel is established to provide Contact with advice and assistance in relation to the monitoring and management of potential adverse effects.[14]

133. With these proposed measures in place the level of residual effect will be negligible or low as set out in **Table 9** below. There will also be a net gain outcome for long-tailed bats in the Catlins from the ICA.

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[14] In the previous consenting process, there was agreement at expert conferencing that an expert bat panel should be established. See Bat-Expert-Conferencing-JWS-reconvened.pdf at [28].

Table 9: Effects matrix and recommended effects management measures

Potential adverse effect	Un-mitigated level of effect	Recommended avoidance, remediation, mitigation or offset/compensation measures	Level of effect after effects management
Habitat removal	Low	Restoration or animal pest control suitable vegetation to create and or enhance the quality of alternative roosting, foraging or commuting habitats. Application of current best practice protocols to check for potential occupied roots can be targeted to old growth stands only, which are not currently within the plantation rotation cycle.	Negligible
Habitat displacement	Low	Enhance habitat for local population through habitat restoration and targeted animal pest control.	Negligible
Potential injury or mortality of bats from turbine strike (including direct effects and 'ecological sink effects)	Low to Moderate in areas of Low / Moderate habitat value (risk of turbine strike is Very Low to Low) Very High in areas of High and Very High habitat value (risk of turbine strike is Moderate)	Implementation of a targeted curtailment regime in the Bat Risk Area. Enhance habitat for local population through habitat restoration and targeted animal pest control.	Low, but only if residual effect management, including pre and post construction monitoring /adaptive management regime and additional compensation applied as required.
Potential injury or mortality of bats from collision with transmission lines	Negligible	None required	Negligible

Curtailment

134. At other wind farm proposals where bat activity is consistently high throughout a year and across all seasons, avoiding all potential strike risk effects by not locating turbines there may be appropriate. However, in this case, activity levels at the Southland Wind Farm are only consistently regular in the months of February, March and April, so avoidance can be achieved in part by using a targeted (or live) curtailment regime.

135. During the Covid Fast-track consenting process, there was agreement between all bat experts that proven live curtailment was preferred over set curtailment.[15] Live curtailment is technology that detects bats flying near or within the rotor-swept zone of an individual turbine through either microphones or (in future) cameras. When combined with Artificial Intelligence, it slows down or turns off turbines when a bat is flying near that turbine.

136. Given the uncertainty regarding live curtailment technology, we recommend trialling acoustically based live curtailment for an initial operating period of up to three years.

137. In contrast to set curtailment regimes, live curtailment technology (if workable) would have the advantage of reducing the amount of time that the turbines are not active when bats are not present. However, this technique is experimental internationally, and highly reliant on monitoring having the ability to switch the turbine off soon enough and/or quickly enough (Rabie et al 2021). Problems associated with live curtailment detection technology includes the efficacy of bat detectors at detecting bats, attenuation of bat calls over relatively short distances, suitable placement of recorders and the ability to switch the turbine off quickly enough to minimise strike risk. Peterson (2020) also noted high variation between the rates at which detectors recorded bats, which would need to be accounted for in any research.

138. Associated monitoring will be necessary to determine the efficacy of the curtailment. We recommend that if the expert bat panel determines from the monitoring that live curtailment is effectively managing adverse effects, that regime should be continued. Conversely, if the expert bat panel determines from the monitoring that live curtailment is not effectively managing adverse

[15] FTC-SWF-expert-conferencing-JWS-ecology-bats.pdf at [50]; Bat-Expert-Conferencing-JWS-reconvened.pdf at [40].

effects, Contact should cease live curtailment and implement set curtailment at the nine turbines identified in paragraph 3(e) and Figure Long-tailed Bats-10 (Part G), from sunset to sunrise between 15 February and 15 April when:

(a) windspeed is 5 m/sec or lower at hub height; and

(b) temperature is 8°C or higher; and

(c) precipitation is less than 1.5 mm/hour.

139. The parameters we have recommended for the set curtailment will eliminate most of the risk associated with each of the identified moderate strike risk turbines that is subject to curtailment. These parameters are conservative, especially considering that some turbine locations within the bat risk area recorded bat presence less than 1% of the total dusk-dawn survey time.

140. We recommend that the curtailment regime is implemented at nine of the eleven turbines within the Bat Risk Area. These nine turbines (identified in paragraph 3(e) and Figure Long-tailed Bats-10 (Part G)) have been identified as posing a relatively higher risk to bats that elsewhere within the wind farm, based on the specific characteristics at these locations and the bat activity data recorded during the ABM surveys. This approach is considered to be appropriate, but precautionary, given the low numbers of bats flying across most of the Wind Farm Site.

141. Based on our extensive surveys and the statistical analysis from Proteus, approximately 85-90% of bat activity occurs above 8^{o}C and 65% of bat activity occurred below 3.75 m/sec at 30 m elevation (which is where wind speed was modelled at every ABM location). This equates to a wind speed of 5 m/sec wind speed at hub height (135m) based on the analysis of the wind data and extrapolation from 30 to 135m elevation. Importantly, this 'cut in' threshold must relate to wind speed at the turbine hub (which is where windspeed will be measured by each turbine) in order to apply curtailment).

142. When rainfall was greater than 2 mm/hr only 3 hours of bat activity was recorded (out of a total of approximately 44,000hrs of recorded bat activity for surveys 5 – 8). Also of relevance is that the precipitation events triggers for felling potential roost trees in the DOC prefelling guidelines[16] have two precipitation triggers – 2.5mm/2hr and 5mm/4hr. The average of these is

[16] Protocols for minimising the risk of felling occupied bat roosts (Bat Roost Protocols) Version 4: October 2024 approved by the New Zealand Department of Conservation's Bat Recovery Group

1.25mm/hour. We therefore consider, on the basis of these two references, that a 1.5 mm/hr as a precipitation trigger to be suitably conservative.

143. Any residual risk will be addressed via the proposed compensation regime, alongside the (already small) risk of turbine strike associated with the turbines that are not proposed to be curtailed.

Compensation package

144. There is strong evidence that undertaking targeted animal pest control within and adjacent to high value habitat will increase bat breeding success. O'Donnell (2017) states: "*Long-tailed bats (Chalinolobus tuberculatus) are critically endangered because of predation by exotic mammals*…" and that: "...*effective predator control is essential for recovering long-tailed bat population*." O'Donnell et al (2017) and Daniel and Williams (1984) indicate this predation occurs predominantly at maternity roosts of long-tailed bats, and animal pest control targeting areas around maternity roosts can result in significant increases in long-tailed bat populations. Their research also showed that landscape wide animal pest control increased survival rates of long-tailed bats.

145. Current knowledge of pest control to assist long-tailed bats has arisen almost entirely from large remote native forests such as Eglinton (Fiordland), Rangataua (Mt Ruapehu), Pureora and Whirinaki (Colin O'Donnell et al., unpub. data, 2023), and research to develop and improve effective pest control to recover bat populations outside of southern beech forests is a first research priority for the Bat Recovery Group (Colin O'Donnell, unpub. data. 2023 in Landcare Research, 2023).

146. Key mammal pest species are (in order of likely importance): ship rats, stoats and weasels; feral cats; and possums.

147. Key sites to target for pest control are maternity roost trees followed by other roost trees. Maternity roosts are those used by one or more bats over the summer period when bats are either heavily pregnant or newly volant (able to fly). They are a high priority for protection because larger numbers of bats gather in them over the summer (Smith et al. 2017).

148. As discussed earlier in our report, radio-tracking work has confirmed the value of the Catlins River area as an ideal focus site for an animal pest control package. This area is known to contain multiple maternal bat roosts, and long-tailed bats would therefore benefit significantly from pest control at

that area. A pest control programme would of course also have significant benefits for other native fauna in that location.

149. We remain of the view that the extent of an animal pest control package should be commensurate to the level of residual effects requiring compensation, while being appropriately conservative. During the Covid Fast-track consenting process, agreement was reached with DOC as to a compensation package that would involve Contact providing DOC with funding to trap the intensive predator control area (a 10,000-hectare area in the Beresford Range) for the life of the Project. The location of that area is set out in Figure Long-tailed Bats-14 (Part G). At expert conferencing there was agreement between all bat experts that the location and size of the intensive pest control area was appropriate and that such a compensation package would be sufficient to address residual risks.[17]

150. The proposed conditions of consent as agreed with DOC (Conditions EC75 – EC79) require the implementation of a Bat Compensation Strategy in respect of the intensive control area, in collaboration with DOC and the Bat Recovery Group. The objectives of the Bat Compensation Strategy are to:

    (a) provide funding to enhance the habitat of a known long-tailed bat population within the Catlins Forest and Beresford Range in particular in order to address any residual effects of the operation of the Southland Wind Farm on long tailed bats;

    (b) provide funding that is able to target predators through trapping and other methods in order to increase the likelihood of successful breeding of the long-tailed bats in this area of the Catlins Forest; and

    (c) provide funding to assist in monitoring the success of the predator control programme by monitoring the Mohua bird (yellow head) population, which is a known indicator of the overall health of the indigenous biodiversity area.

151. To this end we understand that Contact will make a financial contribution to the Bat Compensation Strategy, namely:

    (a) an initial payment to DOC of $300,000, payable upon commencement of construction of the Southland Wind Farm, to assist with the funding required for track building and maintenance, and the purchase of traps

[17] FTC-SWF-expert-conferencing-JWS-ecology-bats.pdf at [55] and [57]; Bat-Expert-Conferencing-JWS-reconvened.pdf at [19], [22] and [41].

and resources to deploy them within the intensive pest control area; and

(b) ongoing annual payments to DOC of $150,000 (inflation adjusted) for the life of the Southland Wind Farm, to assist with ongoing predator control targeted for long-tailed bats and monitoring of efficacy of the predator control.

152. We consider the proposed bat compensation strategy will likely significantly benefit the long-tailed bat population within the Catlins Forest and Beresford Range in particular (and likely other indigenous species also present). This will more than adequately compensate for the residual risk of turbine strike mortality and displacement of bat habitats within the Wind Farm Site.

Monitoring

153. At expert conferencing during the Covid Fast-track process, there was agreement between all bat experts that radio tracking was not required to determine where maternity roosts are within the intensive pest control area as the 10,000 ha is sufficiently large to include many maternity roosting areas.[18] We do not recommend requiring any additional radio-tracking to inform the mitigation strategy and set management measures.

154. Similarly, we do not recommend any additional pre-construction monitoring, beyond any required pre-felling and tree inspections in accordance with the potential roost tree felling protocols detailed in the BMP. We consider that the surveys undertaken provide an adequately designed and statistically robust baseline to inform any future operational monitoring.

155. We do, however, recommend further monitoring during the operation of the wind farm. The actual effect of turbines on the local long-tailed bat population can be accurately measured when the turbines are operational. Bioacoustic monitoring at turbine sites will demonstrate:

(a) if bats associate with turbines;

(b) whether bat activity changes after commissioning; and

(c) whether changes are needed to the curtailment regime.

[18] Bat-Expert-Conferencing-JWS-reconvened.pdf at [26] and [32].

156. The proposed conditions (EC73 and EC74) require post-construction operational bioacoustic surveys with the methodology to be further detailed in the BMP. In accordance with our recommendations, the proposed conditions require:

(a) two bioacoustic surveys to occur annually for a period of five years, and at five yearly intervals thereafter during the operation of the Wind Farm;

(b) the two surveys to be completed between November and April, with at least one of the surveys completed between February and April; and

(c) the expert bat panel to review the results of the post-construction monitoring and determine if any additional monitoring or amendments to the management measures are required.

Carcass searches

157. Carcass searches are standard and well used method to monitor bat and bird strike caused by wind turbines throughout the world. However, given the relatively low detection rates over much of the Wind Farm Site and the nature of the terrain (thick low, dense scrub understory or tall dense plantation forest at the Matariki locations), effective carcass searches may be difficult to achieve in practice. Further, during the Covid Fast-track process, there was agreement between all bat experts at conferencing that carcass searching was unlikely to detect turbine strike events on bats.[19] We do not recommend carcass searches as an effects management measure.

Research, education and outreach

158. Our work on the Project has highlighted that, to date, robust or shared research on the effects of wind farms on New Zealand bat species has not been undertaken. The post-construction monitoring in the proposed conditions will assist in assessing the extent to which long-tailed bats are attracted to wind turbines. During the Covid Fast-track consenting process, there was agreement between all bat experts that hypothesis driven modelling would be a form of research provided the information is publicly available.[20]

[19] Bat-Expert-Conferencing-JWS-reconvened.pdf at [29].
[20] Bat-Expert-Conferencing-JWS-reconvened.pdf at [27]

159. This contribution to understanding and sharing the findings of research would be a significant compensation benefit. Its value should not be under-estimated.

Deterrents

160. As discussed in the literature review, ultrasonic bat deterrents have had some success in deterring bats. However, that success is very species specific and largely untested in New Zealand. We do not recommend the use of ultrasonic deterrents at the Bat Risk Area at this time, but it may be an option to consider in the future.

Gerardus (Gerry) Henricus Anthonius Kessels

Ian Davidson-Watts

APPENDIX ONE – FURTHER DETAILS ON METHODOLOGY

Bioacoustic surveys

0. All ABMs were full spectrum devices with the ability to record all parameters of the calls made by the bats without the need for conversion from ultrasound. In addition, sampling rates and microphone sensitivities/gain could be manually adjusted to ensure consistency. All three ABM detector models have a sensitivity or gain adjustment and this was calibrated for consistency using an ultrasonic sonic chirp and tone (AT100 ultrasonic emitter). Mic sensitivities on the Titley detectors and the gain on the wildlife acoustics detectors were adjusted to calibrate between detectors (ABMs).

1. Using full spectrum ABMs enabled both visual/algorithm inspection of the call parameters using a spectrogram, as well as being able to replay recordings acoustically to confirm the distinctive sounds made by bats, rather than other high frequencies with similar properties that were not bats such as insects, rats, rains etc.

2. Bat echolocation pulses emitted by bats were digitally recorded which provided the sound recording, date, time and ABM reference. ABM models were equipped with GPS/location or a Bluetooth connection with a smartphone app, which also provided a GPS location of the recording. Every ABM was programmed to record for a maximum of five seconds after an initial trigger event which standardised the recording length.

3. The resulting dataset for ABMs provided the total number of five seconds recordings recorded at each ABM for each survey session. These recordings are known as 'bat passes' as they often represented a series of individual bat echolocation pulses as the bat flew within range of the microphone.

4. To account for variation in recording time among ABMs and differences between daylight lengths through the season, a number of metrics to determine bat activity were applied. The standard approach was to calculate bat calls per night (number of bat passes divided by the number of recording nights). To provide a greater understanding of bat activity on the site, other metrics were also used for surveys 5 – 8 including:

   (a) the number of hours bats were present at each ABM;

   (b) the number of nights bat were detected at each ABM; and

(c) whether bats were consistently detected in each survey season were also calculated.

Summer 2023

5. The first three survey sessions were pilot studies and were used to inform the design of a statistically robust and refined study. Twenty ABMs were used for surveys 1 and 2, and 22 ABMs were used for survey 3. The ABMs were located both within and outside the Wind Farm Site, across 43 locations in total:

   (a) nine off-site ABMs and 11 on-site ABMs for survey 1;

   (b) five off-site ABMs and 15 on-site ABMs for survey 2; and

   (c) one off-site ABM and 21 on-site ABMs for survey 3.

6. Due to the detection of bats on the southern boundary of the Wind Farm Site during survey 1, some of the off-site ABMs were re-deployed within the Wind Farm Site during survey 2 with the aim of gaining a better understanding of how extensively bats might be using the Wind Farm Site. This included the redeployment of L5, L7, L8 and L9. Five ABMs; L1, L2, L3, L4 and L10, remained in the same locations outside the Wind Farm Site boundary which generally bordered the Wind Farm Site in native bush areas (podocarp).

7. During survey 3, all but one ABM (L3) were deployed within the Wind Farm Site boundary to maximise the distribution of bats across the site as far as possible. Due to new turbine locations being considered in the southwestern part of the Wind Farm Site, two additional ABMs, L21 and L22, were deployed.

Winter 2023

8. Survey 4 was undertaken to consider whether the escarpment was a key driver of bat activity given the results of surveys 1 – 3. Seventeen ABMs were used. Fifteen ABMs were deployed in the Matariki Forest area at locations considered to be likely foraging habitat based on the initial results of the summer 2023 surveys. Two additional ABMs were deployed in the Tahakopa Valley and Catlins River area in the Catlins Forest Park to provide comparative data in areas known to support long-tailed bat roosting populations.

Further surveys 2023/2024

9. The remaining surveys occurred following discussion with statisticians (Proteus) and reviewing initial survey results. The design of the survey took account of both the locations of the wind turbines and nearby potential bat foraging habitat (based on experience, data from the 2023 surveys and general literature on long-tailed bats). Given the relatively low encounter rates of bats at the site in early 2023 (e.g. compared to the Eastern Catlins Bat Project area), we considered it appropriate, following advice from Proteus, to adopt a paired sampling approach using 80 ABMs. Due to the relatively low bat activity, this approach overall enabled sufficient bat data to be obtained to undertake reliable statistical analysis. One logger was generally placed very close to or near (within 50 m) to a proposed wind turbine location and another ABM was deployed usually between 100 m and 200 m from the turbine site ABM.

10. During survey 5, 40 ABMs were deployed for the first two weeks of November, and then they were moved to the other 40 locations for the second week in November 2023 (resulting in approximately two weeks of monitoring each subset).

11. During surveys 6 – 8, 80 ABMs were deployed simultaneously for approx. two weeks.

12. The ABM locations were selected to ensure site coverage, access limitations and a range of habitats representative of the overall site. The paired 40 sites (80 ABMs) were based on nearest bat habitat within 200m:

    (a) 30 ABMs were located in manuka forest and scrub;

    (b) 26 ABMs were located in exotic conifer plantation forest;

    (c) 16 ABMs were located in scrub; and

    (d) 8 ABMs were located in exotic grassland.

13. Surveys 5 and 6 were designed to monitor the main part of the bat breeding season where pregnant mothers give birth to their single offspring and suckle the young.

14. Surveys 7 and 8 were designed to monitor the period when juveniles are independent and the start of the mating period for bats.

Bioacoustics surveys at height

15. Obtaining bat activity data at the height of rotor sweep area of the turbines proposed for the proposed wind farm is challenging. In addition to the surveys at ground level, an additional ABM was deployed at 80 m height on the 80 m weather mast located at the same location of the ground level ABM – 'MAST ABM'.

16. The mast ABM monitoring was undertaken to take advantage of the weather mast structure to consider whether bats were routinely flying at, or within ABM range of 80 m. The maximum detection range of the ABM is 50m in ideal conditions, meaning the mast ABM could potentially detect any bats flying at 30m or higher.

17. The mast ABM was deployed between 21 November 2023 and 22 January 2024, then again between 19 February 2024 and 25 March 2024.

18. Analysis of the MAST ABM recordings were undertaken in the same way as the ground level ABMs.

Radio-tracking surveys

19. Davidson-Watts Ecology provided the competent bat ecologists and specialist equipment (lures, traps, telemetry equipment and thermal scopes etc) to undertake the bat trapping and radio tracking surveys. Due to the difficult nature of locating bat roosts in trees, the primary approach was to trap free flying bats and radio track individual bats to locate maternity and other roost types.

20. For both surveys, bats were captured using harp traps placed within forest areas/tree lines habitat (see attached location map showing the trapping locations for the Catlins and Site area). Up to six acoustic lures (e.g. Sussex Autobat) were used to improve catch efficiency in forest habitats (Davidson-Watts and O'Donnell, 2023). The lures emitted synthesised or recorded bat social calls.

21. Female and male bats were fitted with lightweight radio transmitter tags (Biotrack Ltd or Holohil) weighing <5-8% of the weight of the bat using Torbot or similar bonding/latex adhesive.

22. Tagged bats were processed quickly and released within 30-60 minutes of capture provided the glue attaching the transmitter has cured sufficiently.

Bats were tracked using a Sika receiver (Biotrack Ltd., Wareham, United Kingdom) and 3 or 5-element Yagi antenna or similar. Their day roost locations were determined using the "homing-in"' method (White and Garrott 1990) and triangulation methods using more than one receiver/tracking team.

23. Day roost finding over the extensive forest areas of the Catlins, and the Site was supported through the use of helicopters (Hughes 500) to locate roosts.

24. When bats were tracked to roost sites, subsequent roost exit counts were undertaken using infrared cameras and/or thermal scopes (e.g. Canon XA10/XA25) to determine roost size and status (e.g. maternity roost). Roost attributes such as location, height, species of tree and type of cavity (where appropriate), were recorded.

Limitations

25. For completeness, we note below the limitations associated with the surveys carried out. There are two caveats:

    (a) as noted earlier in this report, there was consensus among bat experts that the surveying was sufficient; and

    (b) we have high confidence in the reliability and quality of the data collected for this project.

Limitations of bioacoustic surveys

26. Weather conditions such as strong winds, heavy rain and low temperature are known to affect/reduce bat activity. A number of nights within the survey sessions were subject to poor weather conditions that would likely limit bat activity due to the adverse impact on flying invertebrates during these conditions. However, all recording nights have been used in the analysis to provide a representative dataset of conditions associated with backcountry areas within Southland. We consider that variations in weather add robustness to the dataset by enhancing the understanding of the different conditions bats in which bats fly at this site. This is important for developing mitigation strategies such as curtailment parameters.

27. Detection range of the ABM depends on a range of factors including the make and model of the microphone, direction of the calling bats in relation to the microphone, amplitude of the calls made by bats and the attenuation of sound. These factors will also vary due to environmental conditions (the

habitat, wind, temperature humidity etc). Based on observations of flying long-tailed bats using similar, but handheld, bat detector systems, bat calls are unlikely to be detected at ranges greater than 50 m in ideal conditions. This means that the surveys are sampling only the locations they are deployed and are unable to give a full account of bat activity across the site.

28. Occasional equipment failure or bad weather such as rain could result in false triggers filling SD cards and draining batteries. Equipment failure or continuous trigger events can result in the loss of data or overwhelming the ABMs storage cards and power reserves. Equipment failure is not an uncommon issue for such surveys given the deployment periods and complex technical equipment involved. However, there were no significant equipment failure / false trigger issues for the bioacoustic surveys.

29. It is important to note that ABMs detect bat calls not the number of bats. For example, one bat could be foraging over a particular location on just one night during an entire survey and thus this one bat could result in an ABM recording dozens calls during that night, but that detector may not detect bats for the rest of the survey event. This means care is needed when seeking to apply the results of bioacoustic surveys to interpret overall levels of bat activity if the site is only being occasionally used by bats, as this site obviously is.

Limitations of radio tracking

30. A combination of triangulation and close approach methods were adopted to increase the accuracy of radio tracking data. A number of factors such as the landform, safe and permitted access to private land, and time bats spent in an area can affect the accuracy of fixes. The sample size of the tracking study was also limited especially with the Site surveys, and as a result the data presented provides the minimum of what is likely to be present. A greater number of bats captured and tagged would likely increase the number and distribution of roosts located.

31. Trapping work was limited due to a later than planned start to the field work (permit related delays), and in combination with the cooler weather conditions associated with late March, this limited the ability to trap and tag more bats. In most cases roosts were located in the daytime. However, emergence surveys of some roosts were not possible due to their challenging topography where the roosts were located along the steep terrain of the Slopedown Escarpment.

Assessing effects

Assessing effects

32. To ensure that bats are protected during the construction and operation of the wind farm an assessment of impact at a site requires a detailed appraisal of:

    (a) the level of bat activity of recorded at the site assessed both spatially and temporally;

    (b) the risk of turbine-related mortality for long-tailed bats recorded at the site during bat activity surveys (this includes determination of flight paths, nearby roost sites, and flight heights); and

    (c) the effect on long-tailed bats population status if predicted impacts are not mitigated.

33. The above information should be interpreted in the context of likely impacts on local populations. Relevant factors that should be considered include whether populations are at the edge of their range, cumulative effects, presence of protected areas designated for their bat interest and proximity to maternity roosts, key foraging areas or key flight routes, including possible migration routes.

34. The effects assessment was done on a 'worst-case' scenario and the following assumptions were made in relation to how the effects assessment was undertaken in terms of turbine strike risk:

    (a) long-tailed bats are flying within the rotor swept area;

    (b) long-tailed bats could be attracted to wind turbines; and

    (c) wind measurement have been modelled at 30m, which is precautionary given bat the majority of bat activity would likely be at lower elevations and in sheltered locations where wind speeds would be lower.

35. It is important to note that even the most bat-active location on the Southland Wind Farm Site had bat activity less than 5% of the total dusk-dawn survey time.

Habitat displacement analysis

36. Quantified this potential effect by:

    (a) determining available habitat removed or altered by the wind farm's construction;

    (b) identifying the value of these habitat types to bats, informed by the data analysis and modelling.

37. To calculate the bat habitat scores within the proposed vegetation clearance footprint, as well as any additional vegetation within the turbine rotor zone (thereby displacing bat habitat), GIS spatial analysis software was used. The clearance footprint, which comprises all roads, turbine pads and other earthwork areas, combined with the additional areas of indicative 160 m diameter turbine rotor zones that were not included in the clearance footprint, were merged and clipped to the site vegetation layer prepared by Wildland Consultants (2023). Planar hectares for each bat habitat were calculated in GIS. Separate area calculations were conducted using a GIS clipping tool both for footprint clearance by habitat class, and for habitat displacement (but not clearance) by habitat class within the rotor zone. The Wildlands vegetation type layer was used, including their definition of the vegetation types, combined with the construction footprint layer and turbine specifications provided by Contact.

Bat-strike risk analysis

38. The bioacoustics surveys illustrated that long-tailed bats use the Wind Farm Site at varying levels of activity both across the Wind Farm Site, with the eastern parts of the Wind Farm Site, along the Matariki Forest escarpment having the greatest levels of bat activity.

39. However, given the limitations of using one metric to identify bat activity, we considered it appropriate to look at the activity data and survey periods and create four "bat activity indices" (**BAI**), which express a range of activity metrics over the site to smooth out the outlier data. This allows for a truer understanding of which ABM locations were most important in terms of representing most utilised localities (and habitats) across the SWF site. It is in effect a measure of regularity of the number of times a bat frequents an area. The BAI are:

    (a) Activity - Bat passes per night

(b) Regularity - Number of nights ABMs detected bats

(c) Activity expressed as hours – every time a bat call was detected per hour

(d) Survey periods – the activity rate per ABM over each survey period

40. The four metrics for each ABM is then 'scored' using statistical indexing. This provides a way of comparing one ABM with another, in a relative sense.

41. We then applied weighting to the four metrics based on our combined professional opinion as to which was most important in terms of understanding bat movement across the site. We considered that the number of nights ABMs detected bats was the most important metric, with hourly detection rates also being important, whereas survey frequency and bat passes per night were less important. Weighting percentages were allocated accordingly. Specifically:

(a) Bat passes per night was weighted 10%. The data suggests a seemingly ad hoc use of the site. High bat calls per night at the levels of this site (overall very low) may still only indicate a few minutes of activity from a single bat. As already explained a lower weighting is designed to reduce the effect of outlier/opportunistic bat behaviour.

(b) Nights with bats passes were weighted 40%. This BAI provides evidence of a site having regular/frequent and consistent bat activity even if rates are low as the detection range of ABMs are very limited, and feeding activity could be taking place just out of range. However, a small number of calls consistently detected at a location indicates a higher level of risk.

(c) Bat per hour was weighted at 30%. As climate was likely to affect bat activity on certain nights, how many hours bats were detected when they were using the site also shows a level of consistent activity that would be higher risk.

(d) Bats present in each season was weighted at 20%. This BAI is quite a coarse approach to determining how frequently bats use the site. However, consistent use through the season of some ABMs would indicate a level of importance for local bats (males etc) rather than those visiting the area later summer/early autumn.

42. These weightings are applied to the individual scores for each metric which in turn provides a 'sum weighted index score' for each ABM. This allows the ABM's to be ranked, based on their overall bat activity significance.

43. The index method derives the index as a relative measure of ranking the locations for each variable based on the location value versus the other data in the set of locations. The method used can sometimes be called standardization, z-score or standard score.

44. The general format of the formula is: Index_value = $(x - \mu) / \sigma$. In this equation, "x" represents the value at the location of interest, "μ" denotes the mean of the data set of all locations, and "σ" represents the standard deviation of all locations. By subtracting the mean from the value and dividing the result by the standard deviation, we obtain the index value for the location. For instance bat passes per night at Site B58 shown as BP_{58} and the complete data set of Bat passes at all locations as BP_{all}.

45. Index_value = (BP_{58}- Mean(BP_{all}))/Standard Deviation (BP_{all}). The individual indices for each location have then been combined using a weighted sum methodology. The weightings for each data source are shown in the column header in Table 4 of the Bat Addendum Report.

46. The basic formula is shown as; Sum_weighted_index_score = A * 0.1+B * 0.4+C * 0.3+D * 0.2. Where the variables are:

(a) A = Index Bat Activity (weighting is 10%)

(b) B = Index Night Activity (weighting is 40%)

(c) C = Index Hour Activity (weighting is 30%)

(d) D = Index Survey Activity (weighting is 20%)

47. For example, for Site B58

(a) A = Index Bat Activity is 2.9

(b) B = Index Night Activity is 3.9

(c) C = Index Hour Activity is 4.2

(d) D = Index Survey Activity is 2.6

(e) Sum_weighted_index_score = A * 0.1+B * 0.4+C * 0.3+D * 0.2 = 3.6

48. The index method aligns the data values to index values that fit a frequency distribution that has a mean of 0 and a standard deviation of 1. Positive values are above the mean of the distribution and negative values are below the mean.

49. **Table 10** below shows the results of the 18 ABM's that have a sum weighted index score greater than zero. Of these nine had a weighted score above one and six above a weighted score above two.

50. Based on our professional judgement, we consider that:

    (a) a summed weighted index score of one or less represents a locality of Very Low risk of potential turbine strike for long-tailed bats;

    (b) a sum weighted index score of greater than one but less than two represented a Low level of potential turbine strike; and

    (c) a sum weighted index score of higher than two representing a locality where there is a Moderate risk of potential turbine blade strike to long-tailed bats.

Table 10:Weighted index score above zero for the results of four aggregated metrics at each ABM site over surveys 5 – 8

Indexed Ranking of Data

		10% weighting	40% weighting	30% weighting	20% weighting	
Rank	ABM	Indexed Bat Activity (based on number of Bat Passes / Night)	Indexed Night Activity (based on number of nights bats recorded)	Indexed Hour Activity (based on number of hours bats recorded)	Indexed Survey Periods (based on number of survey periods bats detected)	Sum Weighted Index Score
1	B58	2.9	3.9	4.2	2.6	3.6
2	B63	3.4	3.1	3.8	2.6	3.2
3	B77	1.4	3.2	3.1	2.6	2.9
4	B52	2.6	2.4	2.5	1.7	2.3
5	B54	0.6	2.3	2.5	2.6	2.3
6	B64	1.6	2.4	1.8	1.7	2.0
7	B72	0.6	2.3	2.0	0.8	1.7
8	B36	6.4	1.1	1.5	0.8	1.7
9	B61	0.2	1.4	0.8	1.7	1.1
10	B74	0.3	1.0	1.1	0.8	0.9
11	B60	0.0	1.2	0.9	0.8	0.9
12	B57	0.4	0.9	0.5	1.7	0.9
13	B79	-0.1	0.8	0.6	1.7	0.8
14	B78	-0.1	0.8	0.6	-0.1	0.5
15	B28	-0.3	0.1	-0.1	1.7	0.3
16	B80	-0.2	0.3	0.3	-0.1	0.2
17	B25	-0.3	0.1	-0.1	0.8	0.1
18	B47	-0.2	0.0	-0.1	0.8	0.1

APPENDIX TWO – LITERATURE REVIEW

0. No publicly accessible studies have investigated the impacts of wind farms on the spatial use of either of New Zealand's native bat species. Therefore, it is not clear what kind of behaviour either native species exhibit toward wind turbines. However, overseas research on similar insectivorous monophyletic bats (microbats) can assist in determining possible effects on long-tailed bats from wind farms.

Effects of operational wind farms on bats with similar behaviour and habitat requirements to long-tailed bats

1. Wind-turbine driven fatalities of microbats have been recorded in many regions of the world including Australia, Canada, USA and Europe (Baerwald et al., 2009; de Lucas et al., 2012; Rydell et al., 2010). From 2000 onwards, 35% of all global multiple bat mortality events were due to collisions with wind turbines (O'Shea et al. 2016).

2. These fatalities are caused by the bats either being struck by turning blades or through barotrauma (internal haemorrhaging of the lungs) resulting from rapid decompression in the vortices behind the moving blade tips (Rollins et al., 2012; Baerwald et al. 2008). Since bat species have low reproduction rates outside the tropics (Barclay et al. 2004), the potential losses caused by wind turbines must be considered as a mortality factor relevant to the population of a species at a landscape level.

3. Wind speed is a weather variable that is consistently reported as a significant factor related to bat mortality at wind farms. Lower speeds (<6 m/s) are frequently associated with higher bat activity and subsequent fatalities (Arnett and Baerwald 2013; Cryan et al. 2014; Hein and Schirmacher 2016).

4. The counting of impact victims at wind turbines is still the only method to determine quantitative data on the mortality of bats at wind turbines. Searches for strike victims are methodologically complex if they are to provide meaningful data and, even in the best case of a daily search, only allow conclusions to be drawn about the collision risk during the entire previous night (Niermann et al. 2015).

5. International literature remains unclear on exactly how many individual bats are injured around the wind turbine rotors and are still able to actively remove themselves from a potential search area for strike victim counts and possibly die later. This could cause an underestimation of the number of strike victims

and the mortality rates that can be derived from them (see also the expert opinions evaluated by Voigt et al. 2020).

Flight heights

6. No studies that primarily investigate flight altitude in New Zealand bats have been conducted to date but there is considerable overseas research on effects associated with wind farms on similar insectivorous bat species.

7. However, a New Zealand study that investigated spatial and temporal variation in long-tailed bat echolocation activity showed bats flying at heights between 4 m and 30 m (Le Roux et al., 2014). According to this study the majority of long-tailed bats living in rural habitats do not fly at an altitude which would make them at risk to collision with most wind turbine rotors (depending on the turbine specification). However, this was just one study on a different location working with a different population of long-tailed bats than that of the potential Southland Wind Farm. Variations in behaviour have been observed in different habitats and different location, as is clear from the presence of long tailed bats in urbanized areas of Hamilton city (Dumbleton and Montemezzani 2020, Aughton 2021, Caskey and Tempero 2022). In the 2018 thermal imaging study (Borkin 2017) found that 88% of 'confirmed bats' and 77% of 'probable bats' were typically commuting and foraging at the top of, or above, the tree canopy cover along the Waikato River bank in southern Hamilton.

8. The insectivorous serotine bat (Eptesicus serotinus) studied in two locations in Denmark, however, has been shown to exhibit a variety of hunting flight altitudes ranging from 1 m to 18 m above ground (Jensen and Miller 1999). The average flight altitude was calculated as 10.7 ± 2.7 m and 6.8 ± 3.6 m, respectively, dependent on the location.

9. Similarly, a study on the potential impact of wind development sites on multiple bat species in the north-eastern USA, demonstrated that the majority of observed bats flew at approximately tree canopy height (Reynolds 2006). In this study, microphones were placed at ground-level, in the upper-canopy zone and at turbine level height. It was shown that 49% of bat passes occurred at ground level, 34% in the canopy zone and 17% of bat passes were recorded at turbine blade level height.

10. However, previous studies in Germany on impacts of wind facilities on bats, such as the non-migratory, insectivorous common pipistrelle (Pipistrellus

pipistrellus, Brinkmann et al. 2006), indicate frequent flying altitudes near wind turbine blades. In this context, bats were shown to fly at altitudes of above 40 m and at wind speeds of up to 10.9 m/s. Similarly, a study on the effectiveness of acoustic bat deterrents at wind farms in the US (Horn et al. 2007) investigated bat activity near the wind turbine rotor swept zone, which extended from 38 m to 120 m above ground. It was demonstrated that most bats (60%) flew below 38 m, however, 34.5% of all observed bats flew between 38 m and 120 m, and 5.5 % flew above 120 m height.

11. In contrast, the medium-sized insectivorous Brazilian free-tailed bats (Tadarida brasiliensis) in Zimbabwe has been shown to perform foraging flights accompanied by feeding echolocation calls at altitudes that ranged from 0 m to 500 m altitude (Fenton and Griffin 1997). These previous studies indicate a markedly variability in flight altitude of bat species. Correspondingly, it has been proposed that bats may be altering the altitudes of their nightly flights in dependence of weather conditions and cloud cover (Dürr and Bach 2004).

Curtailment

Set curtailment

12. The effectiveness of ‘set curtailment’ as a means to reduce strike risk by bats has not yet been tested in New Zealand, but based on overseas research, its effectiveness at reducing turbine strike risk is likely to be high, depending on the parameters used to define turbine shut down. The key parameters used for shutdown are timing, temperature, precipitation and windspeed. A practice used at operational wind farms overseas is to curtail turbine operation at low wind speeds, typically below 6 m/s, during periods of known high bat activity during the time of year and night when they are most active around a wind farm site. This generally occurs from summer to autumn (Arnett et al. 2008, 2011, 2016, Arnett and Baerwald 2013, Hein and Schirmacher 2016, Behr et al. 2017, Martin et al. 2017, Thompson et al. 2017, Hayes et al. 2019, Rodhouse et al. 2019, Adams et al. 2021, Whitby et al. 2021).

13. A study conducted at a wind farm in southern Australia Bennett et al (2022) found that increasing the turbine cut-in speed from 3.0 to 4.5 m/s significantly reduced bat fatalities by 54%. Curtailment was the primary reason for the reduction in mortality. Of particular note, curtailment seemed to be more

effective at reducing mortality of insectivorous micro-bats, similar to long-tailed bats.

Live curtailment

14. As opposed to set curtailment, 'live curtailment' has been adopted in a few European wind farms, but is largely experimental at this stage, and requires the use of advanced detection cameras, radar or bioacoustic microphones, combined with AI technology, to be effective. Off-the-shelf live curtailment technology using thermal and infrared cameras is also available, but extensive trials would be required to test the efficacy of this technology at this site and on New Zealand bat species. Unfortunately, due to the nature of the forested and steep landscape at the Southland Wind Farm, combined with the speed at which long-tailed bats fly, and the time taken to feather a turbine in reaction to this flight speed, live curtailment is likely not feasible at this point in time at this site. However, the use of live curtailment as a suitable avoidance measure should still be left in the mitigation option toolbox, if this technology become practical for New Zealand windfarms in the future.

Deterrence technology

15. The effectiveness of ultrasonic deterrence technology as a means to reduce strike risk by bats has not yet been tested in New Zealand. For several years, deterrence has been discussed as a method to reduce bat flying through wind turbine sites overseas.

16. Its efficacy could be trialled using current technology developed by NRG Systems.[21] The deterrent system emits an ultrasonic acoustic field at frequencies that are similar to those used by bats for communication. This disrupts their ability to receive and interpret their own echolocation calls, making it difficult to navigate their surroundings. By jamming their echolocation systems, bats are discouraged from entering the treated areas and roosting locations. According to a 2020 study by Weaver et al. installing deterrents significantly reduced bat fatalities for *Lasiurus cinereus* and *Tadarida brasiliensis* by 78% and 54% respectively. However, the researchers found that there was no significant reduction in fatalities for other species in the genus *Lasiurius*, showing that deterrents may help reduce the impact of some bat species, but further research is needed to determine how effective they are for specific species.

[21] https://illumination.duke-energy.com/articles/new-technology-helps-protect-bats-from-wind-turbines

17. Other literature suggests that previous deterrence attempts using ultrasonic interference signals were either only successful in some species, or they showed intra- and interspecific success rates that fluctuated greatly over time (Romano et al. 2019). All studies published up to now have also been carried out on American bats. In addition, the only low reduction rates so far (often only in the range of 30% per species and year; Romano et al. 2019) are not sufficient to reliably avoid killing bats at wind turbines. According to the current state of knowledge, this method is therefore currently not a proven means of reducing bat strikes at wind turbines (see also Schirmacher 2020).

18. Theoretically, bats could also be deterred by radar radiation. So far, however, this idea has not been implemented in wind turbines, either with stationary or mobile systems (Arnett and Baerwald 2013), but several companies are now adopting radar based detection technology, although its application on New Zealand bats would require further research.

Compensation or offsetting

19. Although some progress has been made overseas to develop biodiversity offset or biodiversity compensation strategies for the residual impacts of wind farms on bats and their habitats, this research is still in its early stages. To adequately assess the potential impact of a given mitigation strategy, one must have a good understanding of the scale of the problem at hand and of how much previous mitigation efforts have already alleviated the issue, i.e. the level of residual effects. The offset or compensation measures should only be applied once all suitable avoidance and remediation measures have been applied (Maseyk et al 2018). The ability of off-site habitat enhancement or compensation options to offset residual adverse effects is dependent on understanding the wider habitat requirements of the bat species being targeted (in this case long-tailed bats have a very large home range and occupy a variety of different habitats and use of resources over any given year). Thus, sufficient measures to address residual effects may require compensatory measures over a large area and long period of time – perhaps decades.

20. Biodiversity offsetting requires quantification of the effect and quantification of the benefits of the offset, where as compensation measures can either be developed through expert opinion and/or negotiated settlement. Where the impact occurs will also be a necessary factor to consider when providing compensation, as animals affected by the event may come from a wide

range of geographic areas (Hüppop et al. 2006; Voigt et al. 2012; Hammond et al. 2013). Studies should consider the potential benefits and drawbacks of compensation measures in areas other than the wind farm site, taking into account the need to maintain habitat similarity (Behr et al. 2017).

New Zealand Wind Farm consents relating to bats

21. There is only one known operational wind farm in New Zealand that that has consent conditions relating to long-tailed bats – Te Uku Wind Farm.

22. There have been studies on the effects of bats on other wind farms, such as Hauāuru Mā Raki, Kaimai and Kaiwaikawe. The ecological reports, expert evidence, and proposed or consented conditions of these proposed wind farms have also been reviewed as part of this assessment where available.

Te Uku Wind Farm

23. An ecological assessment of the Te Uku site during the pre-consenting and pre-construction phase found the presence of long tailed bats on or near the wind farm site (Boffa Miskell ltd, 2011a; Golder Associates 2011; Kessels & Associates, 2007). The Te Uku wind farm is the first in New Zealand to have post-construction monitoring targeting both avifauna and bats.

24. The Waikato District Council resource consent (252/06) sets out the conditions for the construction and operation of the Project Te Uku wind farm. The avifauna and bat monitoring that takes place after construction responds to condition 6.1(b), which required "*Strike monitoring programmes for long-tailed bats, New Zealand falcon, and other indigenous birds*."

25. The consent conditions required that records be kept and documented of turbine strikes, and that an assessment be made of the effects of the construction and operation of the wind farm on long-tailed bat populations. The strike monitoring program lasted for three years from the date the wind farm became operational. The consent also required ongoing population monitoring of long-tailed bats for the first three years after the wind farm became operational. Population monitoring was to be conducted by way of presence and absence monitoring. Despite conducting mark-recapture monitoring during the pre-consenting monitoring of the wind farm, the practice was discontinued due to no bats caught.

26. Consent condition 6.7 required that the post-construction monitoring be reported on a quarterly basis, in order to summarize the results of the

previous months' monitoring, any specific outcomes of the monitoring, and the proposed monitoring for the following three-month period. The Te Uku wind farm 2014 Post-construction Avifauna & Bat Monitoring has been reviewed as part of this assessment.

Relevance of Te Uku Wind Farm post-construction monitoring

27. During expert conferencing in the previous consenting process, there was agreement between all bat experts that:[22]

    (a) the Te Uku study has provided some interesting insights into bat activity at that wind farm however, it is difficult to interpret the results as being positive or negative in terms of effects on long-tailed bats; and

    (b) each wind farm must utilise its own data and environmental variables to determine risk and effects.

28. The proposed turbines at Southland Wind Farm will have their rotors higher off the ground compared to Te Uku (~50m ground clearance at SWF cf 30m at Te Uku). This increased height will have a mitigating effect on the risk to bats.

Turbine strike risk

New Zealand evidence of strike risk

29. There is no peer-reviewed, published research on the effects of collision risk of wind turbines on long-tailed bats. However, the one study of an operation of the effects of an operational wind farm on bats in New Zealand suggest the effect of collision risk is low. Te Uku wind farm has been built within the home range of a known population of bats. This 28-turbine wind farm is located in the Waikato and was commissioned in March 2011. The turbine dimensions at this site are 80 m high towers with 49 m long blades, which gives a swept rotor area that begins about 30 m above ground level. As we have noted above, the relevance of the Te Uku post-construction monitoring is limited.

30. Post-construction monitoring of avifauna and bats was carried out for three years (Boffa Miskell Ltd, 2014). This wind farm, while being positioned on open farmland, is located in immediate proximity to Pirongia Forest Park, a large area of mature indigenous forest with a known bat population. At the

[22] Bat-Expert-Conferencing-JWS-reconvened.pdf at [18].

completion of the three years of post-construction bioacoustic monitoring, statistical analysis was applied to the pre- and post-construction data. The analysis focused on bat activity not population size. The report concludes that: "*Statistical comparisons between pre and post construction indicate the construction and operation of the turbines is not having a significant impact on the movements of long-tailed bats in the area*." While encouraging at first viewing, caution should be applied when using this report. Bioacoustic monitoring cannot easily monitor the effects of operational windfarms on bats (e.g. Bennett et al 2022). In addition, carcass searching was limited in that the study was unable to detect carcasses as small as of long-tailed bats, as it used humans only, and not trained dogs. This meant that carcass detection trials, which inform the efficacy of the actual searches, did not find any animal carcasses classified by the researchers within the 'tiny' category. In effect this means that even if there was mortality of bats by turbine strike at Te Uku, the carcass searches were unable to detect these events by using humans only.

International evidence

31. By comparison, a review of international studies shows it is probable that long-tailed bats will suffer mortality as a result of interactions with the turbines. Long-tailed bats are nonmigratory, edge/gap-foraging, aerial hawking bats with moderate manoeuvrability (O'Donnell 1999, 2001, Parsons 2001). Based on overseas research (e.g. Baerwald et al 2008), these behavioural characteristics suggest that, as a general proposition, long-tailed bats have a moderate risk of direct impact with turbine blades, or injury/mortality via barotrauma. However, several behaviours exhibited by long-tailed bats likely elevate the risk of turbine mortality from moderate to moderate/high on this species:

(a) Tree roosting: This is a common feature of bat species suffering from turbine strike. It is theorised that bats are investigating turbines as potential roost trees (Kunz et al. 2007). Bats overseas have been found to be attracted to wind turbines. The reasons are unclear, but it could be to forage on increased insect activity in the vicinity of the warm air created by the turbines and/or bats activity searching for roosts and mistaking the turbine structure for a tree roost.

(b) Aerial hawking: Internationally micro-bats commonly forage higher than 35 m above the ground (Kunz et al. 2007), which could be within the rotor sweep zone of some turbine models. The rotor sweep zone of the turbines proposed for the Southland Wind Farm are likely to be at least 45 m above the ground.

(c) Wide ranging: Long-tailed bats cover distances exceeding 10 km while foraging. Therefore, even if the roost tree is far from the turbines they are at risk while foraging.

(d) Preferential foraging along forest edges and linear corridors: Anthropogenically formed vegetation edges are preferred foraging areas for long-tailed bats. The habitat associated with the proposed wind farm contains a number of these areas.

Transmission line

32. In terms of potential bat strike on transmission towers or lines, there is evidence in national or international literature that bat fatalities from power line collision occurs very rarely.

33. Orbach & Fenton (2010) cite only 'anecdotal reports' of bats colliding with other stationary objects including television towers.

34. One bird study in California did however report a single (unidentified) bat found during a search for bird carcasses surrounding a 110 kV transmission line (Dedon et al., 1989).

35. Visual capabilities of insectivorous bats vary considerably, from species with modest acuity to those with high acuity. Light intensities may influence collision as well as behavioural, hormonal and physiological changes during swarming and mating (Orbach & Fenton, 2010).

36. Some species found overseas have exceptional avoidance capabilities. The little brown bat Myotis lucifugus can almost perfectly avoid vertical wires of only 0.3 mm diameter when flying at between 3 and 4.4 m/s (Griffin, 1958:357 cited in Lee et al., 1992) while the trident bat Asellia tridens can reliably negotiate wires as thin as 0.065 mm (Gustafson & Schnitzler 1979 cited in Lee et al., 1992).

37. Avian electrocution occurs when a bird is able to bridge any two energized conductors (Janss, 2000). However, in relation to bats, international literature only reveals regular fatalities of grey-headed flyingfox (Pteropus poliocephalus – endemic to Australia). This very large fruit bat (with a wingspan up to 1 m) is able to bridge energised conductors with its wings

(VGDSE, 2011). Bats with the wingspan of long-tailed bats, being an order of magnitude smaller, are not physically large enough for this to occur.

APPENDIX THREE – REFERENCES & BIBLIOGRAPHY

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APPENDIX FOUR – PROTEUS REPORT

Proteus
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Proteus Client Report: 190

Bat activity at Mimihau wind farm with updated data 2023-2024

Aaron J. Bertoia, Rachel P. Hickcox, Abby E. Bratt, Stefan Meyer, and Darryl I. MacKenzie

Client Report for DW Ecology

14th June 2024

Proteus
PO Box 7
Outram, 9062
New Zealand

E: info@proteus.co.nz
W: www.proteus.co.nz

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1. Executive Summary

Statistical analyses were conducted for long-tailed bat call data collected at Mimihau wind farm site using acoustic bat monitors (ABMs) during four sampling Periods between October 2023 and April 2024.

Six generalised linear (mixed) models (GLM) were fit at three different temporal scales using two measures of bat activity: number of bat calls or presence-absence of bat calls. For the presence-absence measure at all temporal scales, a binomial model was used. For the number of bat detections at all temporal scales, a Tweedie model was used. For the Period and nightly temporal scales, data for each ABM were aggregated across sampling period and night, respectively. Results from each model are summarized below, noting that the period- and nightly-scale analyses are intended to investigate more general, longer-term, relationships, while the hourly-scale analyses investigate more immediate relationships in bat activity. See appendix for a brief GLM overview.

1. **Period, number of bat calls:** Aggregated to the scale of the sampling periods, the Tweedie model revealed a strong negative relationship between the number of bat calls per ABM and average wind speed (across the period), as well as the distance to the nearest river. The distance to the nearest track showed a weak negative relationship. Maximum tree height in a 10m radius around the ABM and elevation both exhibited a weak positive relationship with bat calls per ABM. Additionally, periods three and four showed a strong positive relationship where there were more bat calls during these periods compared to the reference category (period one).
2. **Period, presence/absence:** Aggregated to the scale of the sampling periods, the results from the binomial model indicated a moderately strong negative relationship between the presence of bat calls in the period and the distance to the nearest river, whereas the distance to the nearest track showed a weak negative relationship. Maximum vegetation height and elevation exhibited a weak positive relationship with the presence of bat calls, while periods three and four demonstrated a strong positive relationship. This suggested that there were

more ABM locations with bat calls present in those periods compared to the reference category (period one).

3. **Nightly, number of bat calls:** When data were aggregated by night, the Tweedie model suggested that counts of bat calls had a moderate negative relationship with average nightly wind speed and the distance to the nearest track. Distance to the nearest river exhibited a strong negative relationship. Maximum vegetation height showed a moderate positive relationship with nightly bat calls, while elevation had a weak positive relationship. Consistent with the period scale, there were more counts of bat calls per night during sampling periods three and four compared to the reference category (period one).
4. **Nightly, presence/absence:** At the nightly scale, the binomial model indicated that the presence of nightly bat calls had a moderate negative relationship with average nightly wind speed, a weak negative relationship with distance to the nearest track, and a strong negative relationship with distance to the nearest river. Additionally, the model suggested that elevation and maximum vegetation height had a weak positive effect on the presence of bat calls. Lastly, bat presence was higher during monitoring periods three and four compared to the reference category (period one).
5. **Hourly, number of bat calls:** When analysed at the hourly scale, the Tweedie model suggested that the number of bat calls per hour exhibited a weak negative relationship with hourly wind speed, a moderate negative relationship with distance to the nearest track, and a strong negative relationship with distance to the nearest river. Additionally, the model suggested that bat counts per hour had a strong positive relationship with average temperature, a moderate positive relationship with maximum vegetation height, and a weak positive relationship with elevation. Like the other models, counts per hour were higher in periods three and four compared to the reference category (Period one). Bat calls per hour also showed a weak positive association with northerly winds and counts of calls had a strong relationship with hours from sunset where observations peaked at around 5-6 hours after sunset. Lastly, there was a strong negative relationship between counts of bat calls and the presence of rain.
6. **Hourly, presence/absence:** The results from the hourly binomial model were generally consistent with the Tweedie model, as described above. Specifically, they indicated that the presence of bat calls had a weak negative relationship with hourly wind speed and distance to the nearest track, but a strong negative relationship with distance to the nearest river. Average temperature had a strong positive effect on bat presence while maximum vegetation height had a weak effect. Furthermore, bat presence showed a strong positive relationship with easterly and northerly winds, and the presence of bats had a strong relationship with house from sunset where observations peaked at around 6 hours after

sunset. The presence of bat calls also had a strong negative relationship with the presence of rain, where more calls were present when it was not raining. Like the other models, sampling periods three and four exhibited more calls compared to the reference category (Period one).

All six analyses reported similar trends. Generally, bat activity (call counts or call presence) had a negative relationship distance to the nearest track, and distance to the nearest river, indicating that bat activity tended to be higher in proximity to tracks and rivers. Moreover, bat activity had a positive relationship with maximum vegetation height and elevation, suggesting higher activity at locations with tall vegetation nearby and at higher elevations. Lastly, all models indicated a strong seasonal effect, with more bat activity recorded during periods three and four. In all models but the binomial period model, bat activity had a negative relationship with wind speed.

The hourly binomial and hourly Tweedie models also included wind direction, time of night, the presence of rainfall, and temperature as covariates. Both models revealed that bat activity increased with rising temperatures, peaked between 5-6 hours past sunset, decreased when rainfall was present, and was positively associated with easterly and northerly winds

It is important to note that apparent relationships between the bat activity data and other variables may be influenced by the distribution of the variable values that were observed during the survey periods. For example, hourly wind speed values of between 0 - 23 m/s were recorded across the four sampling periods, and over 50% of the observations were < 5 m/s. Therefore, even in the absence of a relationship between bat activity and wind speed, it should be expected that over 50% of bat activity would be observed when wind speed is <5 m/s. The analyses conducted account for the uneven spread of variable values when estimating a statistical relationship between bat activity and wind speed.

Figures have been provided in the appendix representing the cumulative relationship between bat activity, temperature, and wind speed for the nine ABM locations identified by I. Davidson-Watts and G. Kessels. A reinterpretation of covariate effects has also been provided in the appendix, calculating the value of each continuous covariate that would equate to a halving of bat activity.

2. Non-technical Summary

Models with three different time scales were included: the period scale (aggregated across the entire two-week monitoring session), nightly, and hourly. Results from the period models, the coarsest scale, show more general trends regarding where bats are more or less likely to be. For example, bat activity may be associated with ABM locations that have low average wind speeds or high average temperatures during the two-week period, among other factors. This scale aids in understanding how bats may be utilizing the site in general. On the other hand, the hourly scale provides more precise estimates of bat activity on an hourly basis, providing a more detailed understanding of bat activity throughout the site.

Bat activity was evaluated using two different metrics: number of bat calls or presence-absence of bat calls, at each temporal scale. Hence, a total of six analyses were conducted. Relationships between bat activity and potential covariates were evaluated using generalised linear models (i.e., a form of regression analysis), where it was assumed that number of bat calls followed a Tweedie distribution (Tweedie model), and presence-absence of bat calls followed a Bernoulli distribution (binomial model).

In the following model summaries, covariate effects are presented in terms of the percentage change in predicted metric of bat activity, for the covariates revealed by the models to have meaningful effects. For the Tweedie models, this is the percentage change in the expected number of bat call counts for each 1-unit increase in the predictor variable. For the binomial models, this is the percentage change in the odds of a bat being present for each 1-unit change in the predictor variable.

For example, wind speed was included in the analyses in units of one metre per second (m/s), therefore interpretation of the wind speed effect in a Tweedie model, is the estimated percentage change in the expected number of bat call counts for each metre per second increase in wind speed. The range of percentages represents the range of estimated effects from across the multiple temporal scales (period, nightly, and hourly; although not always in that order) and does not represent a confidence interval. Tables 4.10 and 4.11 show the full model output where the percentage change for each covariate is presented for all models. See appendix for a brief overview of the generalised linear modelling approach.

Models for number of bat calls

Generally, the three Tweedie models predicting the total number of bat calls showed similar results. All models highlighted a negative relationship between the number of bat calls and wind speed, where counts decreased by 8.15-42.88% for each meter per second increase in wind speed depending on the model that was run. As well as a negative relationship with distance to track where counts decreased by 9.52-12.63% for every 100m away an ABM was from a mapped track, while there was a stronger negative relationship with distance from the river, where expected number of bat calls decreased by 35.60-38.74% for each 100m.

All three Tweedie models show a positive relationship between bat call counts and vegetation height where counts increase by 9.42-14.11% for every metre increase in vegetation height. There was also a weak positive relationship with elevation, where counts increase by 1.61-2.02% for every metre increase in elevation.

All three Tweedie models also highlighted that counts of bat detections were 444.66-1002.32% higher in period three and 445.00-624.27% higher in period four compared to period one.

Because the hourly model had more raw observations that were not aggregated by night or period, it contained additional covariates that could not be added to the period or nightly models. As a result, the hourly Tweedie model highlighted a 29.17% increase in bat counts per degree increase in temperature and positively associated with northerly winds. A quadratic relationship was assumed between bat calls and hours after sunset, which is not easily summarised as for the other covariates, although bat activity was estimated to peak approximately 5-6 hours after sunset, and then decline as the night progressed. Lastly the presence of rain had a strong negative effect with a 61.75% decrease in bat activity when rain was recorded during the hour (noting that rain was not recorded specifically at each ABM location).

Models for presence-absence of bat calls

The binomial models provide similar inferences to the Tweedie models, with generally consistent results. The hourly and nightly binomial models highlighted that bat call presence was estimated to have a negative relationship with wind speed where an increase of one m/s decreased the odds of bat call presence by 9.15-17.30%. All three models suggest that the odds of bat call presence decreased by 6.76-8.97% or every 100m away an ABM was from a mapped track, while the relationship was stronger for distance from mapped rivers (28.82-31.06% decrease). All three models also suggest that the odds of detecting a bat increases by 7.25-10.52% for each metre increase in vegetation height and 1.01-1.41% for each metre increase in elevation.

All three models highlighted a 630.02-2402.81% increase in the odds of bat call presence during monitoring period three and a 370.20-400.28% increase during period four compared to period one.

Lastly, like the hourly Tweedie model, the hourly binomial model contained additional covariates and highlighted that the odds of a bat call being present was 21.65% higher per degree increase in temperature, and positively associated with northerly and easterly winds. A quadratic relationship was also assumed between bat call presence and hours after sunset, and as for the Tweedie model, bat activity was estimated to peak approximately 5-6 hours after sunset, and then decline as the night progressed. Lastly, when rain was recorded in the hour a strong negative effect was estimated, with the odds of bat call presence being 57.13% lower than when no rain.

Note that the percentages provided above are not confidence intervals but the range in the size of the effect generated by the multiple different models that were run.

Common results across multiple models

All six models suggested that periods three and four had substantially more bat activity than periods one and two. Additionally, all models highlighted that bat activity was positively associated with vegetation height and elevation. All models also suggest that bat activity is higher at ABMs that are close to mapped rivers and tracks. Lastly, all models except the binomial period model suggested that bat activity decreased as wind speeds rose.

The two hourly models were the only models that included wind direction, time after sunset, temperature, and the presence of rain. Both models suggest that bat activity increases as temperatures rise and is negatively associated with rain and is positively associated with easterly and northerly winds. Lastly, both models suggest bat activity increases until around 5-6 hours past sunset, after which it declines.

Figures have been included in the appendix exploring the cumulative relationship between bat activity, temperature, and wind speed for the nine most active ABM locations, as identified by I. Davidson-Watts and G. Kessels. A reinterpretation of covariate effects has also been provided in the appendix, calculating the value of each continuous covariate that would equate to a halving of bat activity.

3. Methods

Following from a preliminary analysis on long-tailed bat call data at the Mimihau wind farm conducted in 2023 (MacKenzie, 2023), additional data was used to assess (1) what factors influence bat activity at certain locations for proposed wind turbines, and (2) what are the best parameters to use to curtail risk factors of bat interactions with turbines.

3.1 Environmental predictors

A range of variables provided by DWEcology and Roaring40s Wind Power Ltd were assessed to better understand bat activity as detected by Acoustic Bat Monitors (ABMs) at the proposed wind farm site including:

- Sampling period (Oct-Nov 2023 = 1; Jan 2024 = 2; Feb-Mar 2024 = 3; April 2024 = 4)
- Maximum vegetation height at ABM location (m)
- Distance from the nearest pond (hundreds of metres)
- Distance from the nearest river (hundreds of metres)
- Distance from the nearest trail (hundreds of metres)
- Elevation (m)
- Mean temperature (°C)
- Total rainfall (mm)
- Hours since sunset
- Wind speed at 30m (m/sec)
- Wind direction at 30m (separated into S-N and W-E components using cosine and sine radians, respectively)
- Location ID (i.e., ABM ID)

ABM location was specified as a 'random effect,' allowing the model to incorporate additional spatial random variation between locations that may not be captured by other variables in the model. All other variables were included as fixed effects.

Distance to nearest, pond, river, and track were generated with the *st_nearest_feature* function from the *sf* [v1.0-14; Pebesma (2018)] package, which calculates the distance in meters to the closest feature of each shapefile to the location of each. The distance variables were then scaled by converting to 100s of metres.

Vegetation height was generated by LIDAR. First, height values were extracted for each ABM location. Some locations had negative height values that were very close to zero, so these values were set to zero. Then, a 10 m radius buffer was created around each ABM location, and the maximum vegetation height was calculated. This maximum vegetation height was used in the models, following a discussion with the client.

Wind direction was converted from degrees to radians, then split into S-N and W-E components using the cosine and sine functions, respectively. Transformed values range from -1 to 1, with negative values indicating a southerly/westerly direction and positive values indicating an northerly/easterly direction, with the pair of values indicating wind direction. For example, a south-westerly wind would have the pair of values (cosine, sine) = (-1, -1), while a northerly wind would have the values (1, 0).

Following MacKenzie (2023), two general approaches were taken: 1) analysing the number of bat calls, and 2) examining the presence or absence of bat calls. For each approach, three models were run: 1) where observations were aggregated to the ABM location per period (320 observations); 2) where observations were aggregated to the ABM location per night (5580 observations), and 3) where ABM-specific hourly observations were not aggregated (70743 observations). This yielded six models in total: period, nightly, and hourly models of either total bat calls or the presence-absence of bat calls. These two approaches were employed to evaluate the consistency of the results across different data treatments, given the significant variation observed in the number of bat calls per hour.

3.2 Modelling

For the period and nightly temporal scales, data for each ABM were aggregated across sampling period and night, respectively. The methods used are summarised briefly below:

Bat activity was measured in two ways, (1) the number of bat calls per hour and (2) the detection (i.e., presence/absence) of bats per hour at each ABM, across three different temporal scales: (1) hourly, (2) nightly, and (3) sampling period. The number of bat calls per hour was summed for each night and for the four sampling periods. Bat call presence was a binary variable, where presence was determined if at least one call was recorded during the hour, night or period, for the respective analysis temporal scale. Note that analyses at the period- and nightly-scale were intended to evalate more general, longer-term, relationships, while the hourly-scale analyses assess more immediate relationships that may be suitable to inform possible curtailment strategies.

Analyses of bat call data were conducted using generalised linear mixed models (GLMMs). GLMMs are a form of regression used to quantify the effect that a set of predictor variables has on a response variable (e.g., the number or presence-absence of bat calls; see appendix for a brief overview). GLMMs can also be used for prediction, where in this case, bat call count or presence may be predicted as a function of covariates. GLMMs accommodate 'random effects' by treating the influence of each factor level as a random value sampled from a normal distribution. This requires estimating only the standard deviation of the distribution, as opposed to a 'fixed effect,' which entails estimating specific parameters for each factor level. A random effect allows for specific sources of variation in the data due to the study design, such as repeated measures from the same ABM over time, to be accounted for. It also allows for more flexible predictions. In this case, treating ABM location as a random effect allows for predictions incorporate the uncertainty associated with location to predictions of bat call count or presence at locations without ABMs.

The number of bat calls was assumed to follow a Tweedie distribution, which is a discrete-valued distribution similar to a Poisson distribution but with greater flexibility for describing variation in the data and well-suited for data with an excess of zeros. The presence/absence of bat calls were assumed to follow a binomial distribution, with a maximum of only 1 detection per temporal unit (i.e., hour, night or period).

All data manipulation and analyses were performed in *R* (v4.3.2; R Core Team (2021)) using packages associated with *tidyverse* (v2.0.0; Wickham et al. (2019)). All models were fit using the package *glmmTMB* (v1.1.8; Brooks et al. (2017)).

3.2.1 Period models

For the two models that were aggregated to the sampling period *average wind speed*, *maximum vegetation height*, *elevation*, *distance from nearest track*, *distance from nearest pond*, and *distance from nearest river* were included as continuous variables while *sampling period* was categorical. *Temperature* and *rainfall* were not included in these models, since they were highly correlated with each other and to *sampling period*. *ABM location* was included as a random effect in the aggregated model of the number of bat calls; however, in the presence-absence model, this random effect accounted for very little additional random variation. Consequently, the ABM location random effect was removed from the binomial model as it was adding unnecessary complexity without improving the model fit.

3.2.2 Nightly models

For the two models aggregated to the night-level, *average wind speed*, *maximum vegetation height*, *elevation*, *distance from nearest track*, *distance from nearest pond*, *distance from nearest river*, and *elevation* were included as continuous variables while *sampling period* was categorical. *ABM location* was also included as a random effect. As with the period models, *temperature* and *rainfall* were strongly correlated with *sampling period* and were therefore excluded from the models.

3.2.3 Hourly models

For both hourly models, *wind speed*, *maximum vegetation height*, *distance from the nearest track*, *distance from the nearest pond*, *distance from the nearest river*, and *elevation*, were included as above. Additionally,*average temperature*, *total rainfall*, *hours since sunset*, and *wind direction* were included as continuous variables. *Sampling period* was included as a categorical variable and *ABM location* was included as a random effect as above.

3.2.4 Model Fit

The model fit was evaluated by comparing predicted values to observed data. Model predictions, such as counts or bat presence/absence, were sorted into 20 bins based on their predicted values, each bin representing 5% of the overall dataset. The data were then combined at the bin level, and the observed values were averaged. Ideally, if the model fits perfectly, the average observed data should closely match the binned predicted values. The resulting figures depict the predicted versus observed data in scatter plots, providing a visual assessment of how well the model predictions align with the actual observed data (see Section 4).

4. Results

4.1 Bat data summaries

Selected summaries of the data are given below. Figure 4.1 shows the relative frequency of bat call presence by period and, conditional on presence, the number of bat call detections per day.

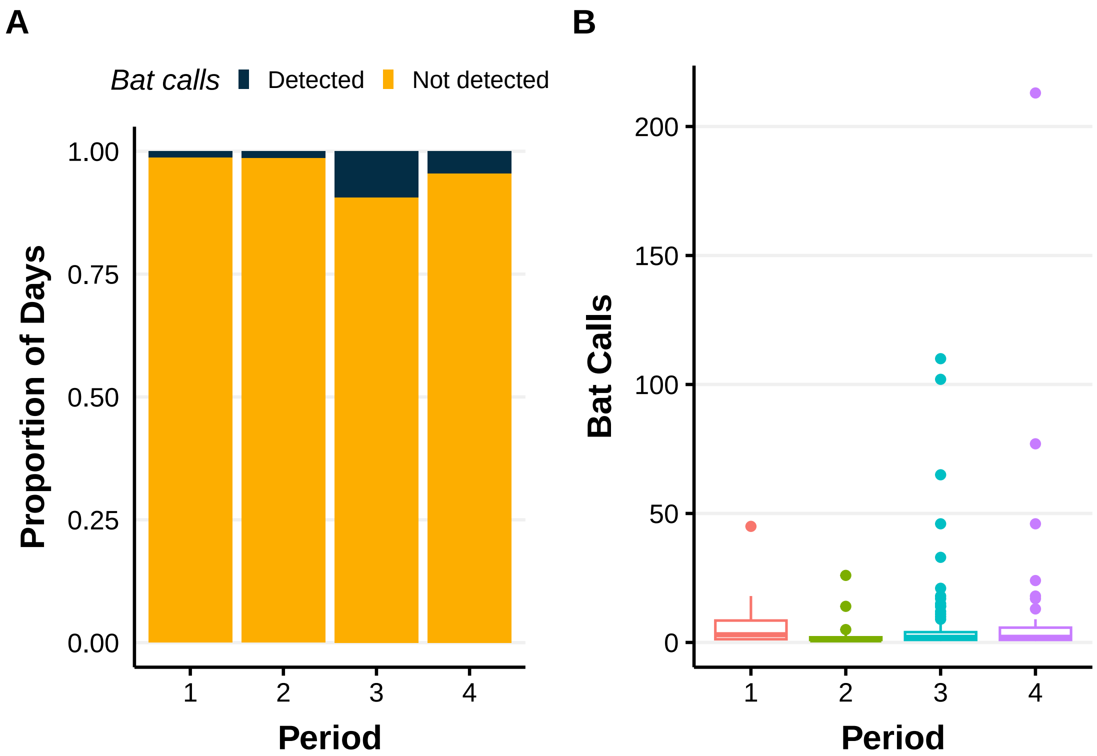

Figure 4.1: Proportion of logger days in each sampling period with bat calls detected (A). Conditional on bat calls being detected, distribution of total daily number of bat calls by period (B).

4.1.1 Predictor variable percentiles

We summarised the recorded hourly values for the dynamic environmental variables wind speed, average temperature, and total rainfall into percentiles in 10% intervals across all sampling period and for each of the four sampling periods (Tables 4.1-4.3). We also calculated percentiles for hourly values when at least one bat call was recorded, to better show the distribution and variability in the variables when bats were present.

Table 4.1: Wind speed (m/s) values at different percentiles for all hourly data and for hourly data where the number of bat calls is greater than 0. Percentiles are provided for all sampling periods (Overall) and for each individual period.

Percentile	Overall	Period 1	Period 2	Period 3	Period 4
All hourly observations					
0	0.03	0.04	0.08	0.03	0.09
1	0.43	0.35	0.52	0.38	0.49
5	1.03	0.90	1.27	0.94	1.08
10	1.50	1.43	1.83	1.32	1.56
20	2.26	2.13	2.73	1.94	2.45
30	2.99	2.72	3.60	2.60	3.21
40	3.69	3.29	4.38	3.27	3.90
50	4.43	3.84	5.16	4.12	4.62
60	5.28	4.46	6.00	5.16	5.51
70	6.28	5.19	7.00	6.35	6.44
80	7.50	6.20	8.17	7.72	7.50
90	9.27	8.08	9.98	9.64	8.89
95	10.84	10.06	11.48	11.32	10.11
99	13.94	14.10	14.55	14.30	12.64
100	22.73	22.73	22.49	21.60	17.36
Bat calls > 0					
0	0.16	0.33	1.01	0.17	0.16
1	0.22	0.42	1.02	0.21	0.39
5	0.61	0.80	1.04	0.53	0.66
10	1.01	1.33	1.12	0.98	1.01
20	1.62	1.79	1.30	1.47	2.23
30	1.94	1.92	1.68	1.82	3.04
40	2.47	2.14	2.20	2.27	3.34
50	3.00	2.69	2.96	2.71	3.64
60	3.45	3.23	3.24	3.10	4.11
70	4.11	4.01	4.65	3.64	5.70
80	5.03	4.95	5.09	4.59	6.51
90	6.51	6.38	6.23	5.80	7.60
95	7.50	6.69	6.71	6.61	8.17
99	10.60	8.53	9.92	9.05	10.54
100	12.35	9.02	10.89	12.35	11.12

Table 4.2: Average temperature (°C) values at different percentiles for all hourly data and for hourly data where the number of bat calls is greater than 0. Percentiles are provided for all sampling periods (Overall) and for each individual period.

Percentile	Overall	Period 1	Period 2	Period 3	Period 4
All hourly observations					
0	1.26	1.74	1.26	2.54	2.86
1	2.35	1.95	2.41	2.83	2.95
5	3.37	2.52	4.47	3.87	3.46
10	4.00	3.08	5.60	4.43	3.87
20	5.46	4.00	7.52	6.47	4.78
30	6.53	4.73	8.98	7.61	5.82
40	7.35	5.86	9.46	8.27	6.56
50	8.48	6.98	9.95	8.84	7.01
60	9.32	7.49	10.97	9.59	7.74
70	10.28	8.91	12.61	10.44	9.14
80	11.88	10.18	13.64	12.10	11.10
90	13.67	11.82	15.37	14.51	12.46
95	15.01	13.18	16.59	14.97	13.48
99	17.13	15.23	17.63	17.17	16.33
100	19.14	16.88	19.14	19.03	16.54
Bat calls > 0					
0	4.49	4.82	5.99	6.39	4.49
1	5.25	5.13	6.74	7.85	4.98
5	7.63	6.29	9.21	8.24	5.65
10	8.16	6.49	9.53	8.31	7.67
20	8.39	7.42	10.31	8.78	8.24
30	9.48	7.83	12.49	9.59	9.14
40	10.14	8.09	13.12	10.08	10.77
50	10.78	8.89	14.20	10.44	10.88
60	12.04	10.38	15.46	12.33	11.45
70	13.41	11.25	15.60	13.69	12.23
80	14.06	11.68	16.44	14.10	13.41
90	14.99	13.01	16.61	14.85	15.19
95	15.51	13.17	16.74	14.99	15.93
99	16.59	14.75	17.19	15.74	16.54
100	17.33	15.17	17.33	15.74	16.54

Table 4.3: Total rainfall (mm) values at different percentiles for all hourly data and for hourly data where the number of bat calls is greater than 0. Percentiles are provided for all sampling periods (Overall) and for each individual period.

Percentile	Overall	Period 1	Period 2	Period 3	Period 4
All hourly observations					
0	0.00	0.0	0.00	0.0	0.00
1	0.00	0.0	0.00	0.0	0.00
5	0.00	0.0	0.00	0.0	0.00
10	0.00	0.0	0.00	0.0	0.00
20	0.00	0.0	0.00	0.0	0.00
30	0.00	0.0	0.00	0.0	0.00
40	0.00	0.0	0.00	0.0	0.00
50	0.00	0.0	0.00	0.0	0.00
60	0.00	0.0	0.00	0.0	0.00
70	0.00	0.0	0.00	0.0	0.00
80	0.00	0.0	0.00	0.2	0.20
90	0.40	0.2	0.60	0.6	0.60
95	1.00	0.6	1.80	1.4	1.00
99	2.80	2.2	3.00	3.8	2.00
100	6.80	3.6	4.80	6.8	2.20
Bat calls > 0					
0	0.00	0.0	0.00	0.0	0.00
1	0.00	0.0	0.00	0.0	0.00
5	0.00	0.0	0.00	0.0	0.00
10	0.00	0.0	0.00	0.0	0.00
20	0.00	0.0	0.00	0.0	0.00
30	0.00	0.0	0.00	0.0	0.00
40	0.00	0.0	0.00	0.0	0.00
50	0.00	0.0	0.00	0.0	0.00
60	0.00	0.0	0.00	0.0	0.00
70	0.00	0.0	0.00	0.0	0.00
80	0.00	0.0	0.00	0.0	0.00
90	0.00	0.0	0.00	0.0	0.00
95	0.00	0.0	0.00	0.0	0.53
99	1.93	0.0	1.82	0.6	1.83
100	2.60	0.0	2.40	2.6	2.00

4.1.2 Predictor variable distributions

Consideration of the distribution of predictor variable values provides context to apparent relationships with bat activity in the observed data. Bat activity may appear to be greater within a given range of values simply as a consequence of there being more hours where those conditions were recorded relative to other variable values. The statistical method used in these analyses account of the unequal distribution of variable values, hence are more likely to esimate actual relationships. Figures 4.2-4.10 provide an overview of the distribution of hourly values for the spatio-temporal predictor variables utilised in the subsequent analyses. Of particular note, rainfall had a skewed distribution with 0mm of rain for the majority of hourly observations. Each figure contains plots of hourly values for each variable containing all data (4.2A-4.10A), as well as a subset of the data only containing values when bats were detected (Figures 4.2B -4.10B).

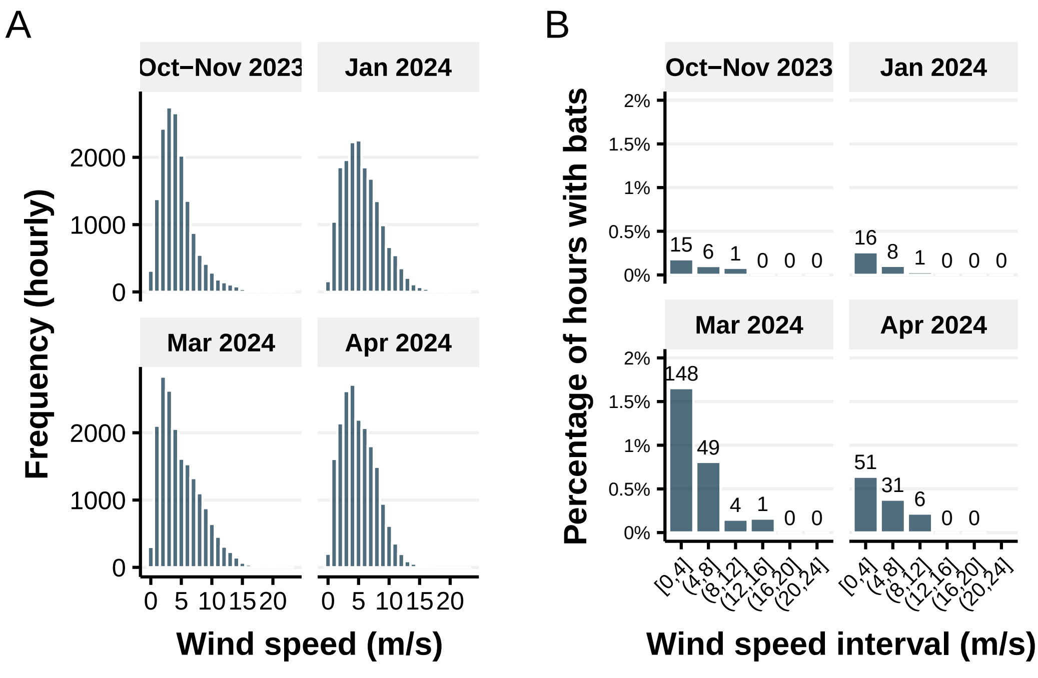

Figure 4.2: Distribution of hourly wind speeds (m/s) at ABM locations for each period. Figure A represents all available data, while Figure B represents the percentage of hours when bats were present from the total available hours in the study. The numbers above each bar in Figure B represent the number of hours that bats were present in each bin.

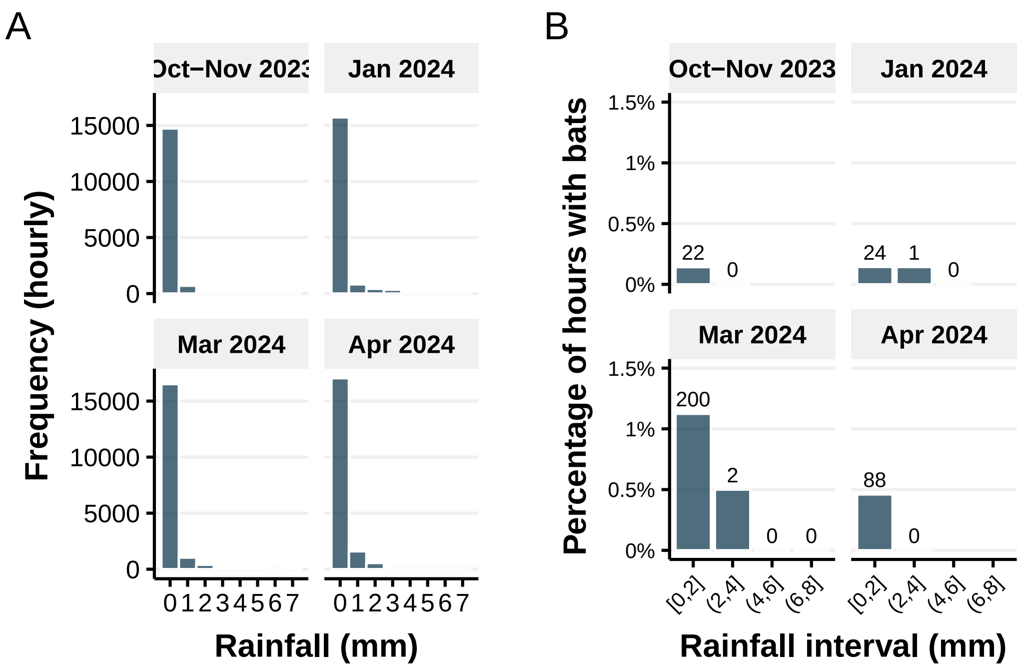

Figure 4.3: Distribution of hourly rainfall (mm) at ABM locations for each period. Figure A represents all available data, while Figure B represents the percentage of hours when bats were present from the total available hours in the study. The numbers above each bar in Figure B represent the number of hours that bats were present in each bin.

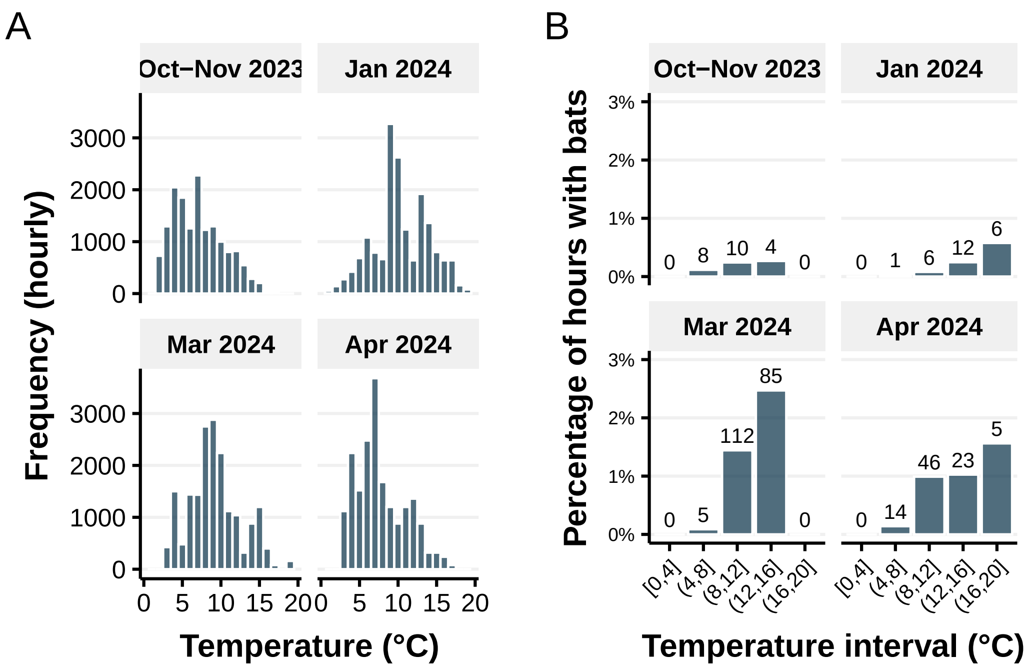

Figure 4.4: Distribution of average hourly temperature (°C) at ABM locations for each sampling period. Figure A represents all available data, while Figure B represents the percentage of hours when bats were present from the total available hours in the study. The numbers above each bar in Figure B represent the number of hours that bats were present in each bin.

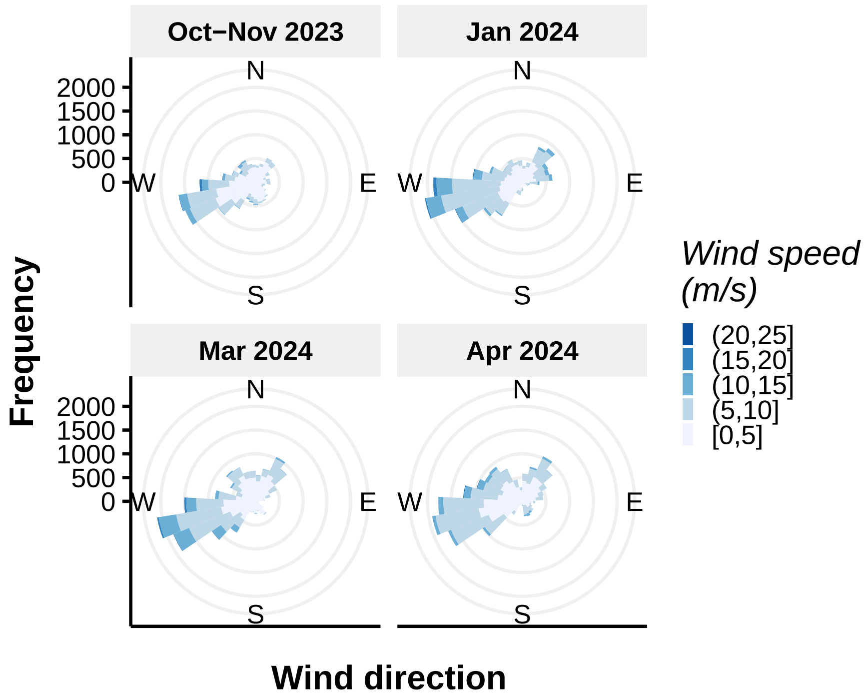

Figure 4.5: Distribution of the direction (degrees) and speed (m/s) across all hourly observations at all ABM locations for each sampling period. Histogram bar height corresponds to the frequency of a given wind direction and bar color corresponds to the proportion of observations at a given wind direction with a given wind speed, where darker colors indicate faster wind.

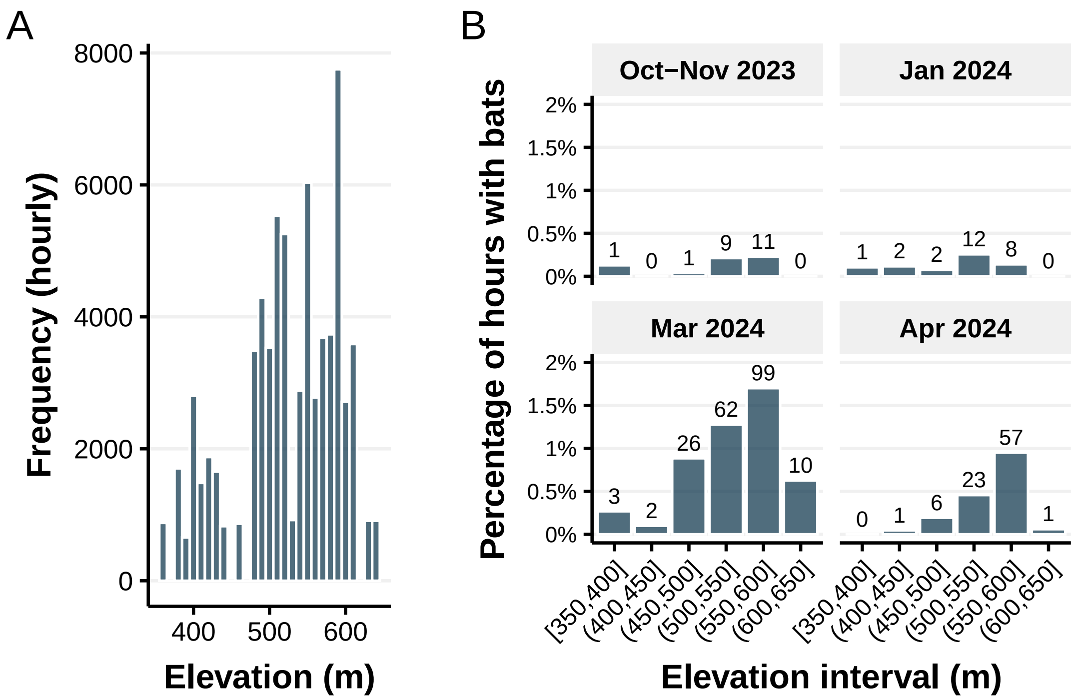

Figure 4.6: Distribution of elevation (m) at ABM locations. Figure A represents all available data, while Figure B represents the percentage of hours when bats were present from the total available hours in the study. The numbers above each bar in Figure B represent the number of hours that bats were present in each bin.

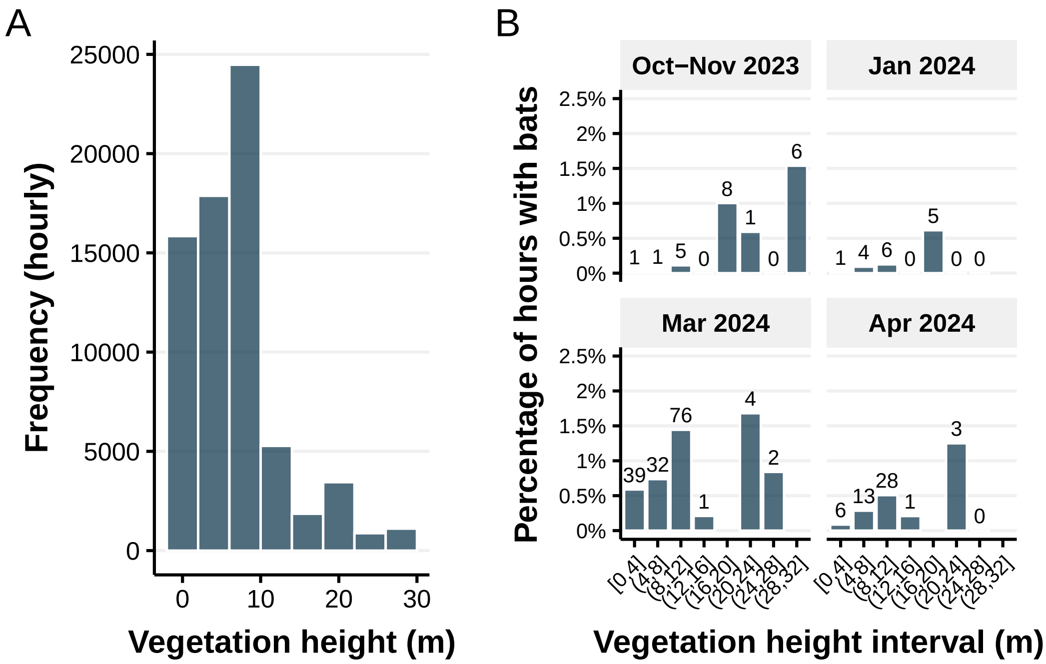

Figure 4.7: Distribution of vegetation height (m) at ABM locations. Figure A represents all available data, while Figure B represents the percentage of hours when bats were present from the total available hours in the study. The numbers above each bar in Figure B represent the number of hours that bats were present in each bin.

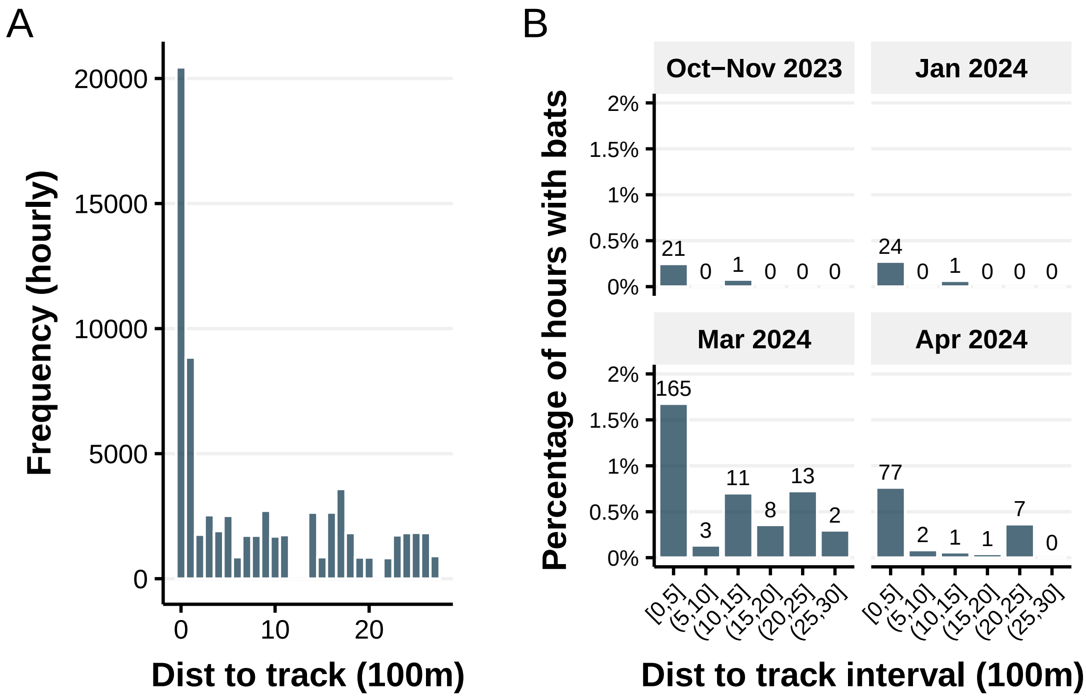

Figure 4.8: Distribution of distance to nearest feature (hundreds of metres) at all ABM locations. Figure A represents all available data, while Figure B represents the percentage of hours when bats were present from the total available hours in the study. The numbers above each bar in Figure B represent the number of hours that bats were present in each bin.

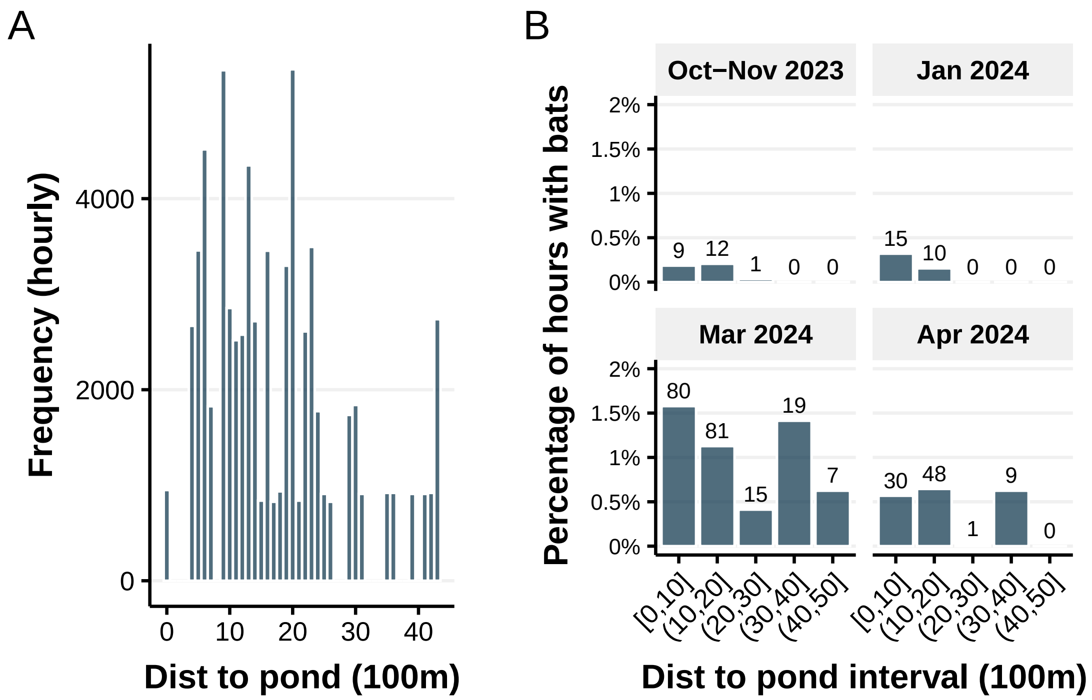

Figure 4.9: Distribution of distance to nearest feature (hundreds of metres) at all ABM locations. Figure A represents all available data, while Figure B represents the percentage of hours when bats were present from the total available hours in the study. The numbers above each bar in Figure B represent the number of hours that bats were present in each bin.

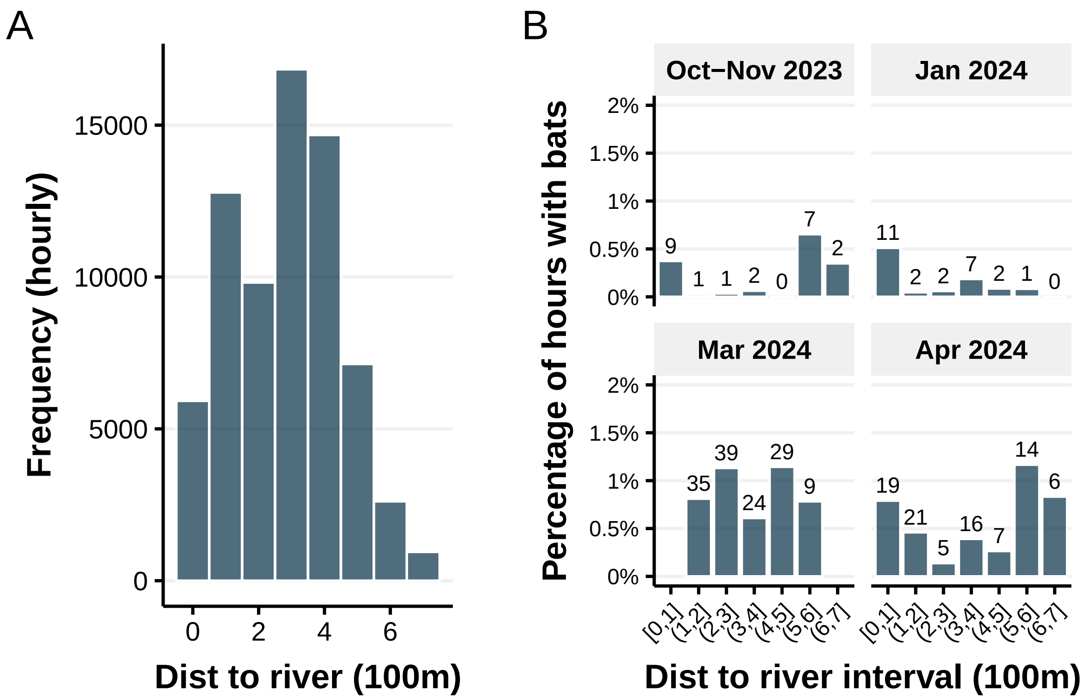

Figure 4.10: Distribution of distance to nearest feature (hundreds of metres) at all ABM locations. Figure A represents all available data, while Figure B represents the percentage of hours when bats were present from the total available hours in the study. The numbers above each bar in Figure B represent the number of hours that bats were present in each bin.

4.2 Period models

4.2.1 Number of bat calls

The number of bat calls per ABM location was assumed to follow a Tweedie distribution. Table 4.4 shows the results of the GLMM which includes all environmental parameters. The model suggests a strong positive effect of sampling period, particularly periods 3 and 4, indicating temporal variation in bat activity across the periods (Figure 4.11). Note that the effect of period is relative to the reference period (period 1). Average wind speed and distance to tracks and rivers had negative effects on the number of bat calls. Distance to track had a weak effect while distance to rivers, and average wind speed had a strong effect. Elevation was estimated to have a weak positive effect, as did vegetation height. The random effect also showed substantial variability in the response variable between ABMs (SD = 1.18). Figure 4.12 shows model predictions for each variable, while holding all other variables constant at their mean value.

Figure 4.13 highlights that the majority of locations have little to no bat detections, where the model does a good job of predicting bat observations at those lower levels. When there were larger numbers of bat observations (60-150), the model can both over and underestimate bat activity, which should be expected as the intent of the model is to predict average levels of bat activity for given combinations of covariate values.

For a numeric representation of model fit R^2 have been included alongside the figures depicting model fit. Note that biology and ecology differ from other natural sciences in that they deal with living organisms influenced by a wide range of biotic and abiotic factors. Consequently, the amount of variance accounted for by a single factor or group of factors in a model can be relatively small. Models often exhibit unexplained variation because it is impossible to record and incorporate everything that influences animal behavior into a single study or analysis. Therefore, statistics representing model fit, such as R^2, are often lower than in other sciences like chemistry or physics, where the amount of variance explained by a controlled experiment is usually large.

Table 4.4: Estimated fixed-effect generalised linear mixed model coefficients fitted to the total number of bat calls per hour sampling period. The acoustic bat monitor ID (i.e., location) was used as a random effect. Blue p-values are <0.05.

Term	Est	SE	95% CI	t-value	p-value
(Intercept)	-7.91	2.14	[-12.11, -3.7]	-3.69	<0.01
WindSpeed (m/s)	-0.56	0.18	[-0.91, -0.21]	-3.12	<0.01
VegHeightMax (m)	0.09	0.04	[0.01, 0.16]	2.19	0.03
DistanceTrack (100m)	-0.10	0.04	[-0.18, -0.01]	-2.32	0.02
DistancePond (100m)	0.04	0.04	[-0.03, 0.11]	1.02	0.31
DistanceRiver (100m)	-0.44	0.17	[-0.78, -0.11]	-2.59	0.01
Elevation (m)	0.02	0.00	[0.01, 0.03]	3.87	<0.01
Period[2]	0.15	0.47	[-0.77, 1.08]	0.33	0.74
Period[3]	2.40	0.35	[1.72, 3.09]	6.91	<0.01
Period[4]	1.95	0.36	[1.24, 2.66]	5.41	<0.01

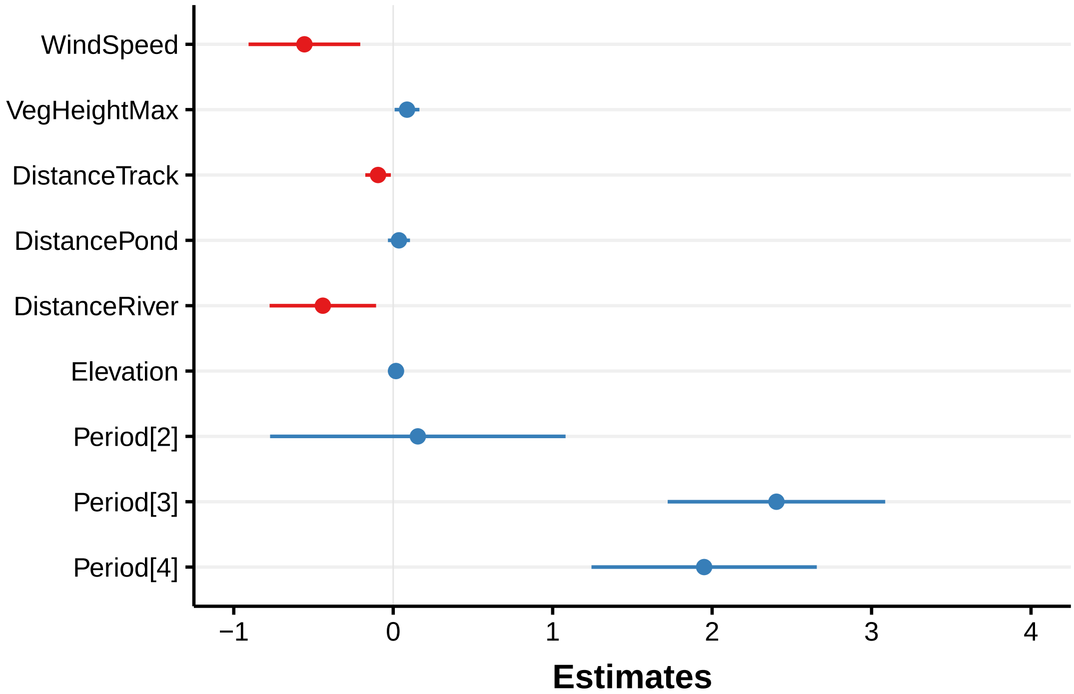

Figure 4.11: Plot of the coefficients for predictor variables in the generalised linear mixed model for the total number of bat calls per sampling period at each ABM. Positive coefficients (blue) indicate a positive association with the response variable, while negative coefficients (red) suggest a negative association. The horizontal error bars represent 95% confidence intervals.

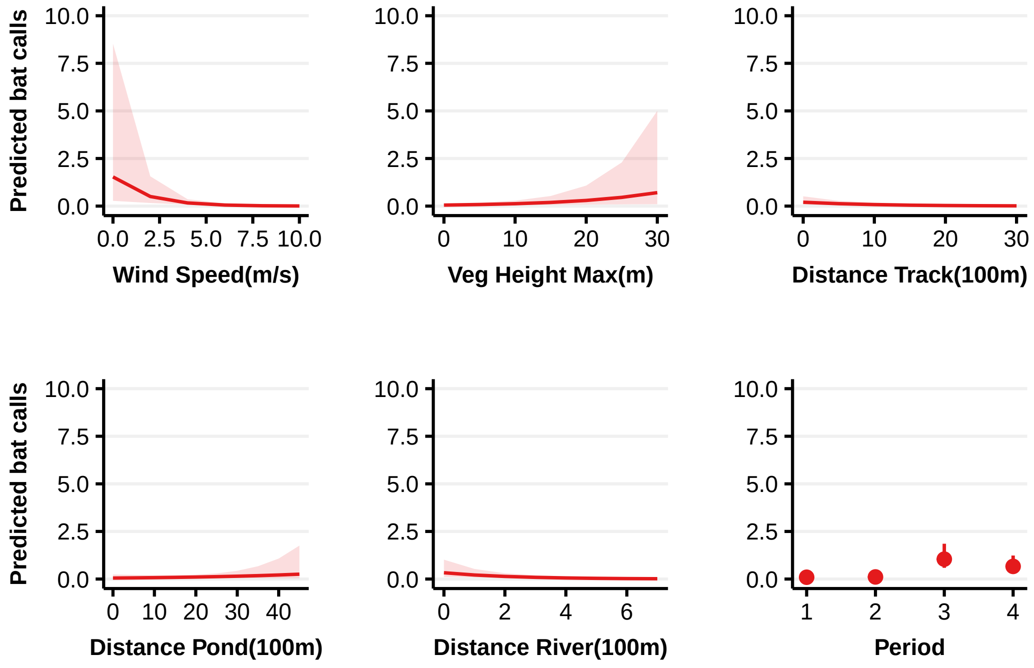

Figure 4.12: Plot of the estimated marginal effects for predictor variables in the generalised linear mixed model of the number of bat calls on the period scale. The plot represents the predicted average number of bat calls holding all other variables constant at the mean. The red shaded area indicates the 95% confidence interval.

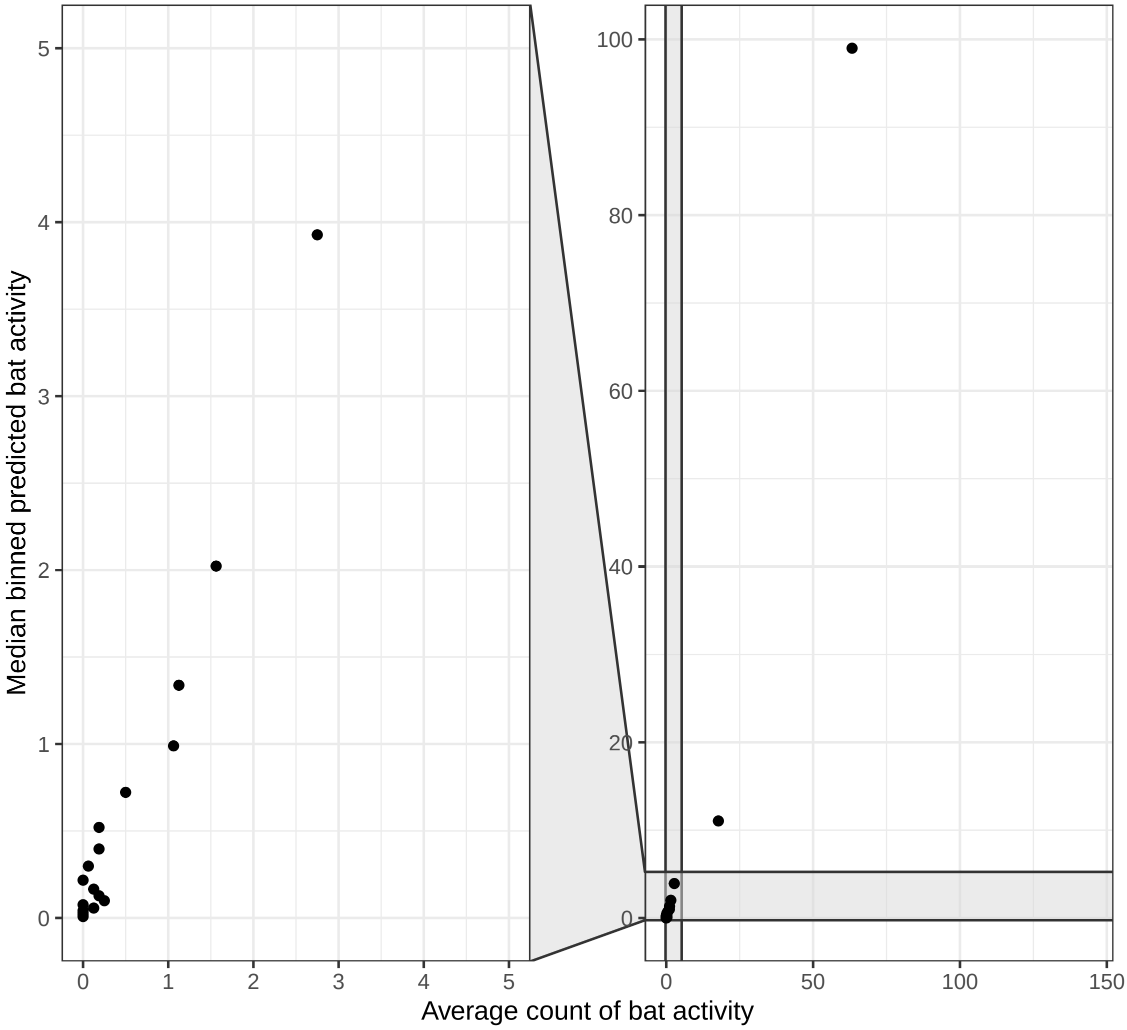

Figure 4.13: Plot of the period-level Tweedie model-based binned predicted number of bat calls and the average observed value in that bin. The R^2 for the model is 0.47.

4.2.2 Bat call presence/absence

The presence/absence of bats per ABM location was assumed to follow a binomial distribution. Table 4.5 shows the results of the GLM. In a binomial GLMM, the coefficients represent the change in the log-odds of the response variable (presence of bats) for a one-unit change in the predictor variable. For example, an increase of wind speed by 1 m/s would decrease the odds of detecting a bat by approximately 6%.

Consistent with the results from the Tweedie model of bat call counts, the binomial model suggests a strong positive relationship between the presence of bats and sampling period, particularly period 3 and 4, indicating temporal variation in bat presence between those periods and period 1. Note that the effect of period is relative to the reference period (period 1). There were also weak positive effects of elevation and vegetation height. Lastly, distance to track and river both had negative effects where the relationship for distance to track was weak and the relationship for distance to river was strong. Table 4.15 shows model predictions for each continuous variable, while holding all other variables constant at their mean value.

Figure 4.16 shows that model predictions from the binomial period model are fairly consistent with the observed data.

Table 4.5: Estimated fixed-effect generalised linear mixed model coefficients fitted to the presense of bat calls per sampling period. Blue p-values are <0.05.

Term	Est	SE	95% CI	t-value	p-value
(Intercept)	-8.14	1.61	[-11.46, -5.12]	-5.05	<0.01
WindSpeed (m/s)	-0.17	0.13	[-0.43, 0.08]	-1.35	0.18
VegHeightMax (m)	0.10	0.03	[0.04, 0.16]	3.20	<0.01
DistanceTrack (100m)	-0.07	0.03	[-0.13, -0.03]	-2.88	<0.01
DistancePond (100m)	0.01	0.02	[-0.04, 0.05]	0.26	0.79
DistanceRiver (100m)	-0.36	0.12	[-0.6, -0.14]	-3.15	<0.01
Elevation (m)	0.01	0.00	[0.01, 0.02]	4.13	<0.01
Period[2]	1.01	0.56	[-0.05, 2.15]	1.82	0.07
Period[3]	3.22	0.53	[2.25, 4.33]	6.10	<0.01
Period[4]	1.60	0.52	[0.61, 2.68]	3.05	<0.01

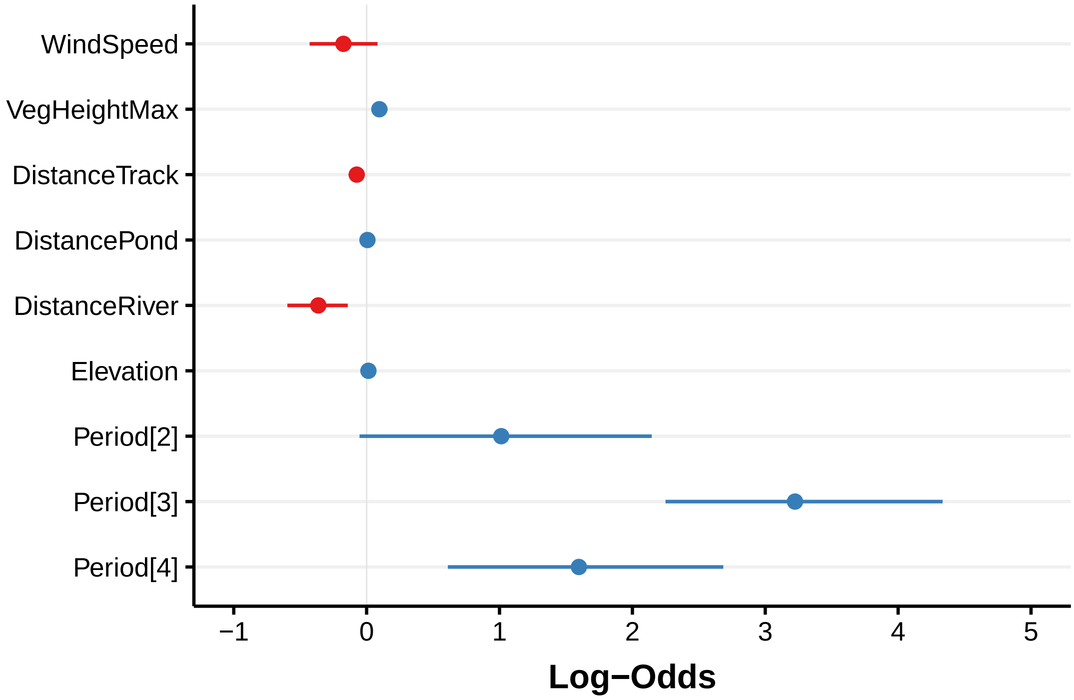

Figure 4.14: Plot of the log-odds for predictor variables in the generalised linear mixed model for the presence/absence of bat calls per sampling period at each ABM. Positive coefficients (blue) indicate a positive association with the response variable, while negative coefficients (red) suggest a negative association. The horizontal error bars represent 95% confidence intervals.

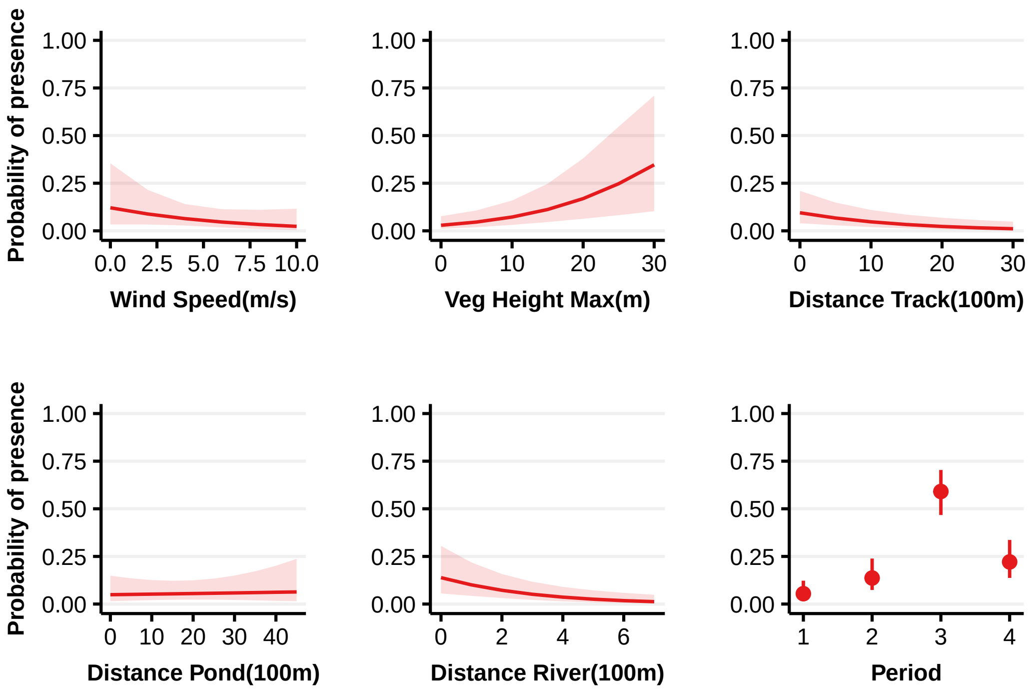

Figure 4.15: Plot of the estimated marginal effects for predictor variables in the generalized linear mixed model of the presence of bat calls on the period scale. The plot represents the predicted average probability of bat calls being present, holding all other variables constant at the mean. The red shaded area indicates the 95% confidence interval.

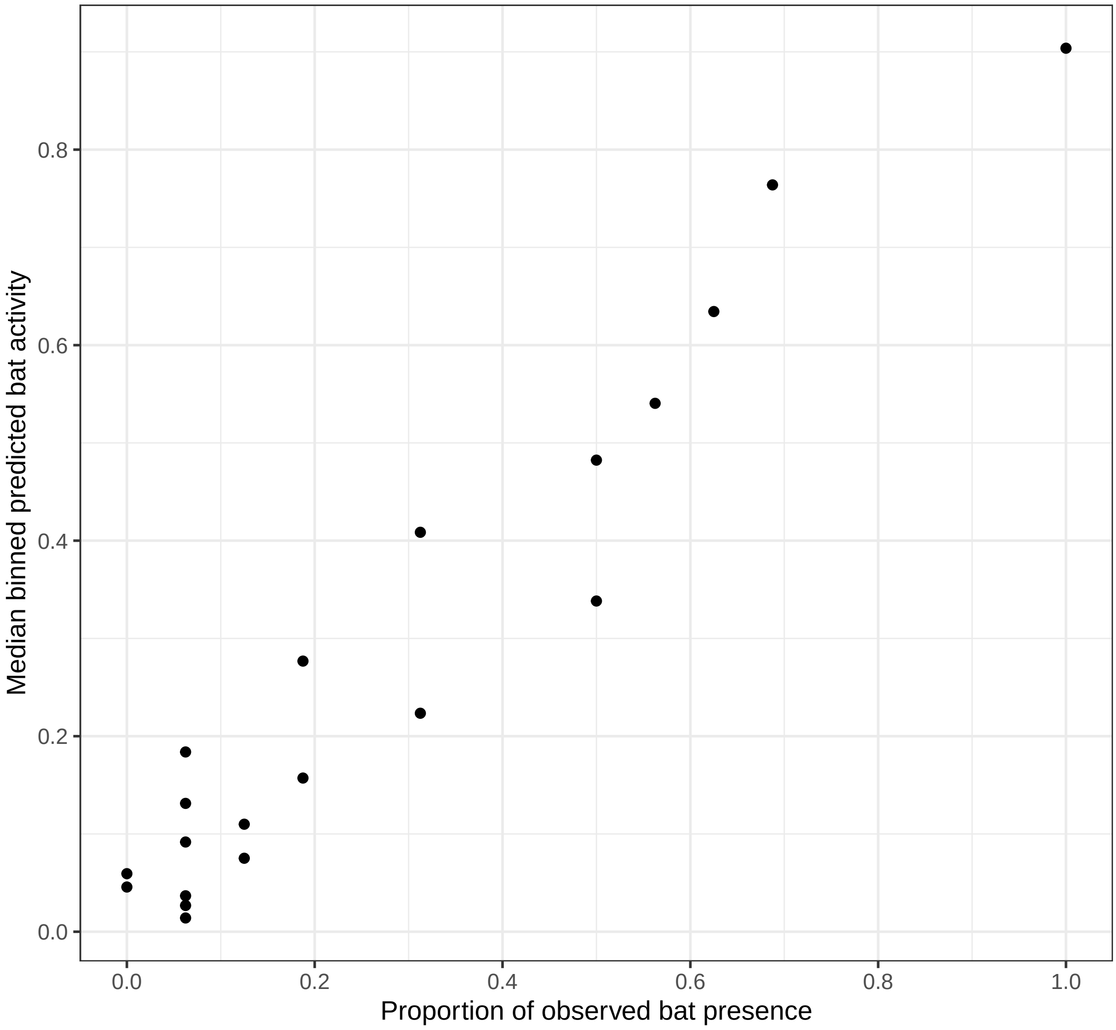

Figure 4.16: Plot of the period-level binomial model-based binned predicted number of bat calls and the average observed value in that bin. The R^2 for the models is 0.34.

4.3 Nightly models

4.3.1 Number of bat calls

As above, the nightly number of bat calls per ABM location was assumed to follow a Tweedie distribution. Table 4.6 shows the results of the GLMM which includes all environmental parameters. In general, the results at the nightly scale are consistent with the results at the period scale, though the effect sizes and associated uncertainty are slightly different. The model suggests a strong positive effect of sampling period, particularly periods 3 and 4, indicating temporal variation in bat activity across the periods (Figure 4.17). Note that the effect of period is relative to the reference period (period 1). Average wind speed and distance to tracks and rivers had negative effects on the number of bat calls. Distance to track and average wind speed had relatively weak effects while distance to rivers had a strong effect. There was also a weak positive effect of maximum vegetation height and elevation. The random effect showed substantial variability in the response variable between ABMs (SD = 1.48). Figure 4.18 shows predicted model predictions for each variable, while holding all other variables constant at their mean value.

Figure 4.19 shows that the model makes fairly accurate predictions when observed bat counts were low, but is less accurate when observed values are high.

Table 4.6: Estimated fixed-effect generalised linear mixed model coefficients fitted to the total number of bat calls per hour night. The acoustic bat monitor ID (i.e., location) was used as a random effect. Blue p-values are <0.05.

Term	Est	SE	95% CI	t-value	p-value
(Intercept)	-11.95	2.17	[-16.2, -7.71]	-5.52	<0.01
WindSpeed (m/s)	-0.16	0.05	[-0.25, -0.06]	-3.26	<0.01
VegHeightMax (m)	0.12	0.04	[0.04, 0.2]	2.86	<0.01
DistanceTrack (100m)	-0.12	0.04	[-0.2, -0.04]	-2.81	<0.01
DistancePond (100m)	0.03	0.04	[-0.04, 0.1]	0.96	0.34
DistanceRiver (100m)	-0.49	0.18	[-0.84, -0.14]	-2.72	0.01
Elevation (m)	0.02	0.00	[0.01, 0.02]	3.45	<0.01
Period[2]	-0.25	0.36	[-0.95, 0.46]	-0.69	0.49
Period[3]	2.37	0.28	[1.81, 2.92]	8.42	<0.01
Period[4]	1.98	0.29	[1.4, 2.56]	6.74	<0.01

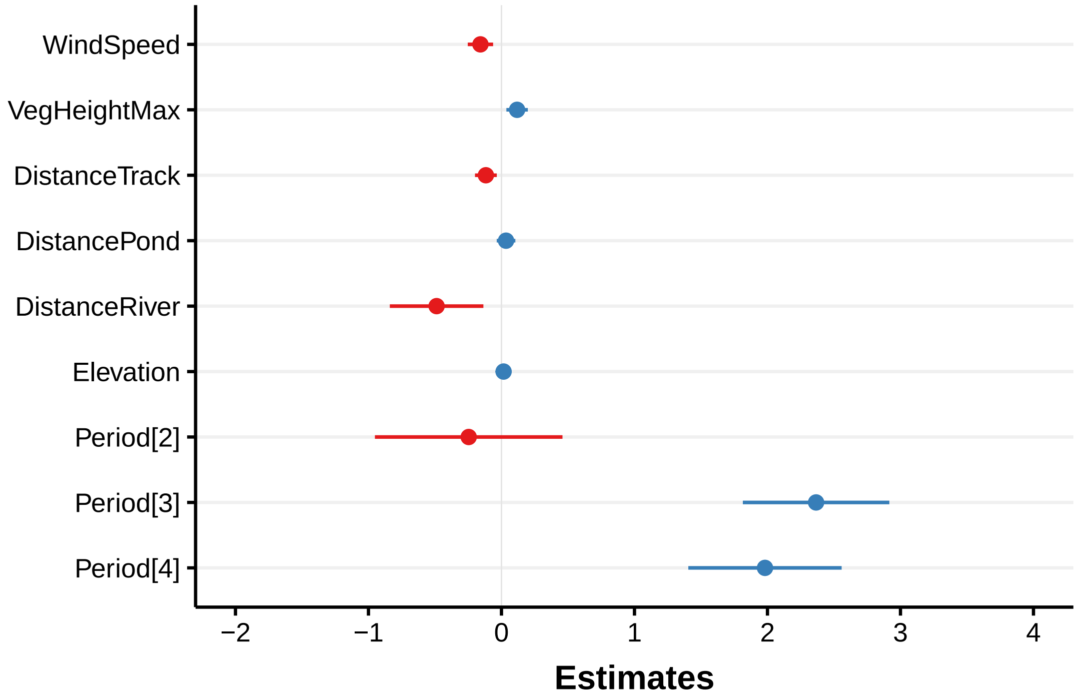

Figure 4.17: Plot of the coefficients for predictor variables in the generalised linear mixed model for the total number of bat calls per night at each ABM. Positive coefficients (blue) indicate a positive association with the response variable, while negative coefficients (red) suggest a negative association. The horizontal error bars represent 95% confidence intervals.

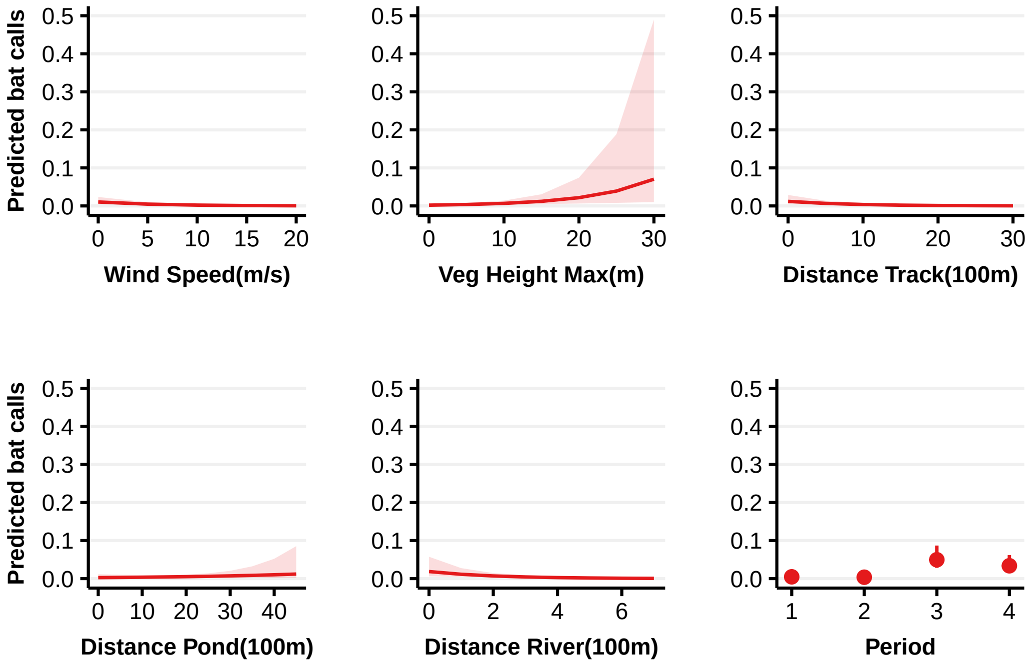

Figure 4.18: Plot of the estimated marginal effects for predictor variables in the generalised linear mixed model of the nightly number of bat calls. The plot represents the predicted average number of bat calls holding all other variables constant at the mean. The red shaded area indicates the 95% confidence interval.

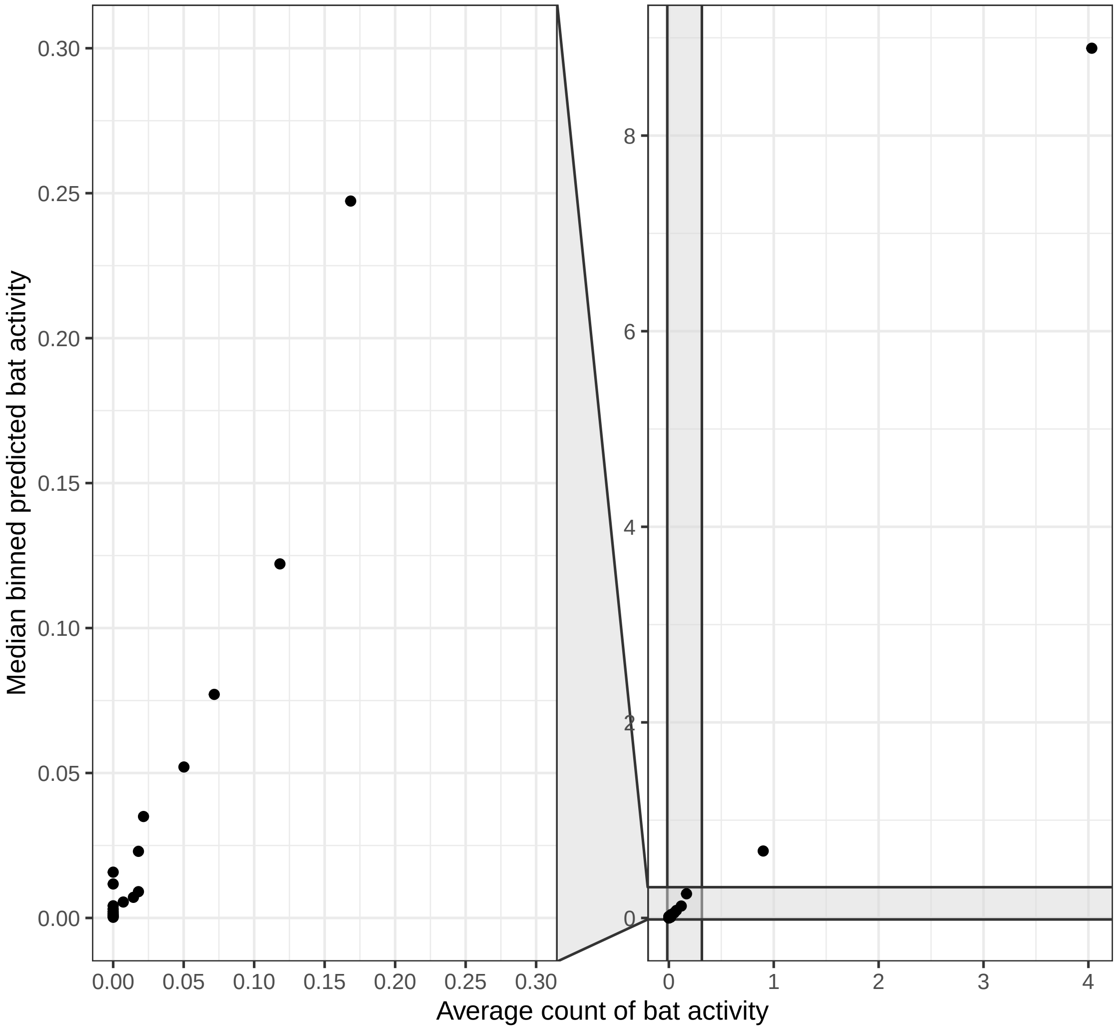

Figure 4.19: Plot of the night-level Tweedie model-based binned predicted number of bat calls and the average observed value in that bin.The R^2 for the model is 0.34.

4.3.2 Bat call presence/absence

As above, the presence/absence of bats each night per ABM location was assumed to follow a Bernoulli distribution. Table 4.7 shows the results of the GLM. Consistent with the results from the other models, the nightly binomial model suggests a strong positive positive relationship between the presence of bat calls and sampling period, particularly period 3 and 4, indicating temporal variation in bat call presence across the periods. Note that the effect of period is relative to the reference period (period 1). Wind speed distance to tracks and rivers all had a negative effect on the presence of bat activity where the relationship was weak for wind speed and distance to track, but strong for distance to rivers. Elevation and vegetation height on the other hand had weak positive effects on bat call presence. The random effect also showed substantial variability in the response variable between ABMs (SD = 0.94). Table 4.21 shows model predictions for each continuous variable, while holding all other variables constant at their mean value.

Figure 4.22 shows that the model is fairly accurate at predicting nightly bat call presence across the full range of values, but may slightly overestimate bat call presence when observed values are higher.

Table 4.7: Estimated fixed-effect generalised linear mixed model coefficients fitted to the presense of bat calls per sampling night. Blue p-values are <0.05.

Term	Est	SE	95% CI	t-value	p-value
(Intercept)	-10.63	1.50	[-13.58, -7.68]	-7.07	<0.01
WindSpeed (m/s)	-0.19	0.04	[-0.25, -0.12]	-5.23	<0.01
VegHeightMax (m)	0.07	0.03	[0.02, 0.12]	2.72	0.01
DistanceTrack (100m)	-0.08	0.03	[-0.14, -0.03]	-3.08	<0.01
DistancePond (100m)	0.01	0.02	[-0.03, 0.06]	0.64	0.52
DistanceRiver (100m)	-0.34	0.12	[-0.56, -0.11]	-2.92	<0.01
Elevation (m)	0.01	0.00	[0.01, 0.02]	4.14	<0.01
Period[2]	0.35	0.33	[-0.3, 1]	1.06	0.29
Period[3]	2.53	0.27	[2, 3.06]	9.35	<0.01
Period[4]	1.61	0.29	[1.05, 2.17]	5.65	<0.01

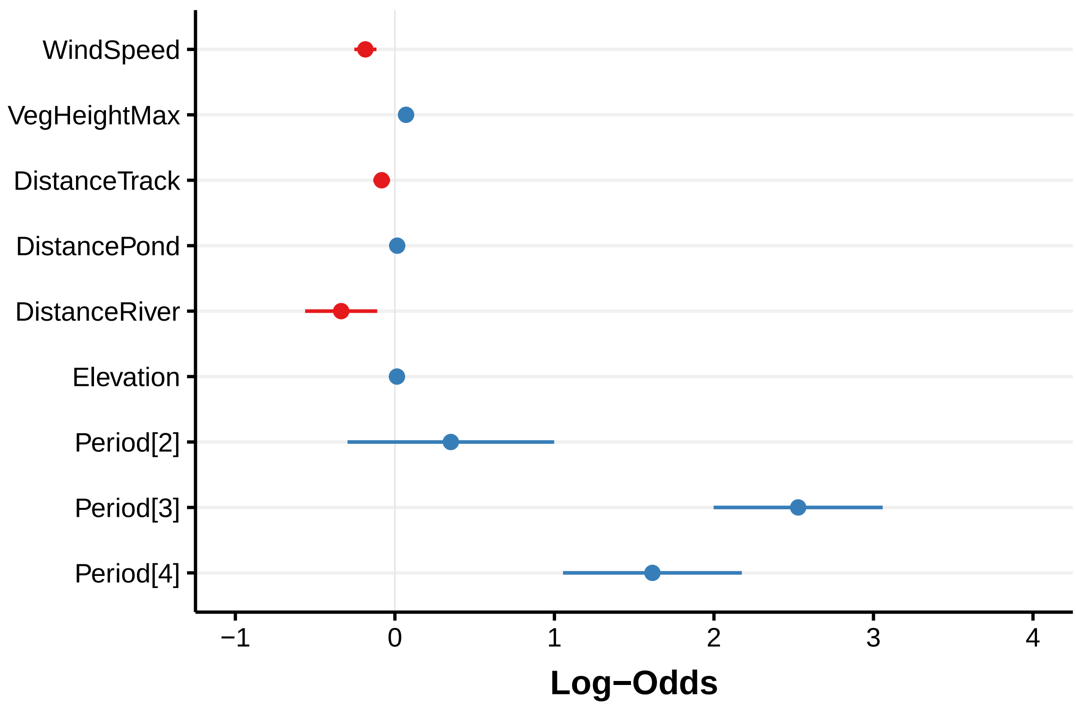

Figure 4.20: Plot of the log-odds for predictor variables in the generalised linear mixed model for the presence/absence of bat calls per night at each ABM. Positive coefficients (blue) indicate a positive association with the response variable, while negative coefficients (red) suggest a negative association. The horizontal error bars represent 95% confidence intervals.

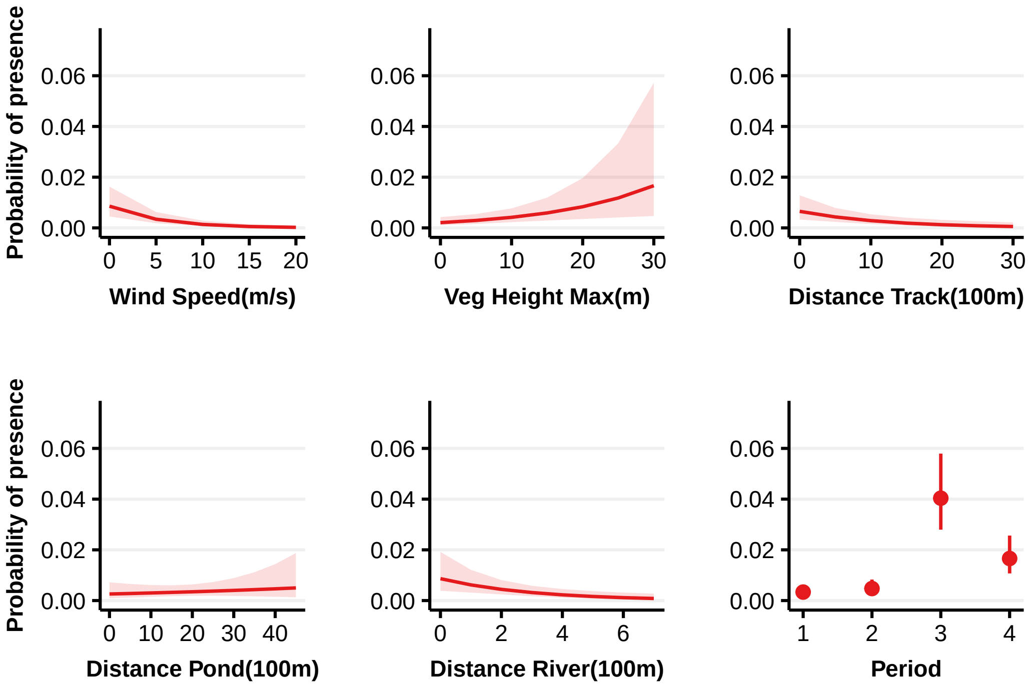

Figure 4.21: Plot of the estimated marginal effects for predictor variables in the generalized linear mixed model of the presence of bat calls on the nightly scale. The plot represents the predicted average probability of bat calls being present, holding all other variables constant at the mean. The red shaded area indicates the 95% confidence interval. Note the y-axis does not extend from 0-1.

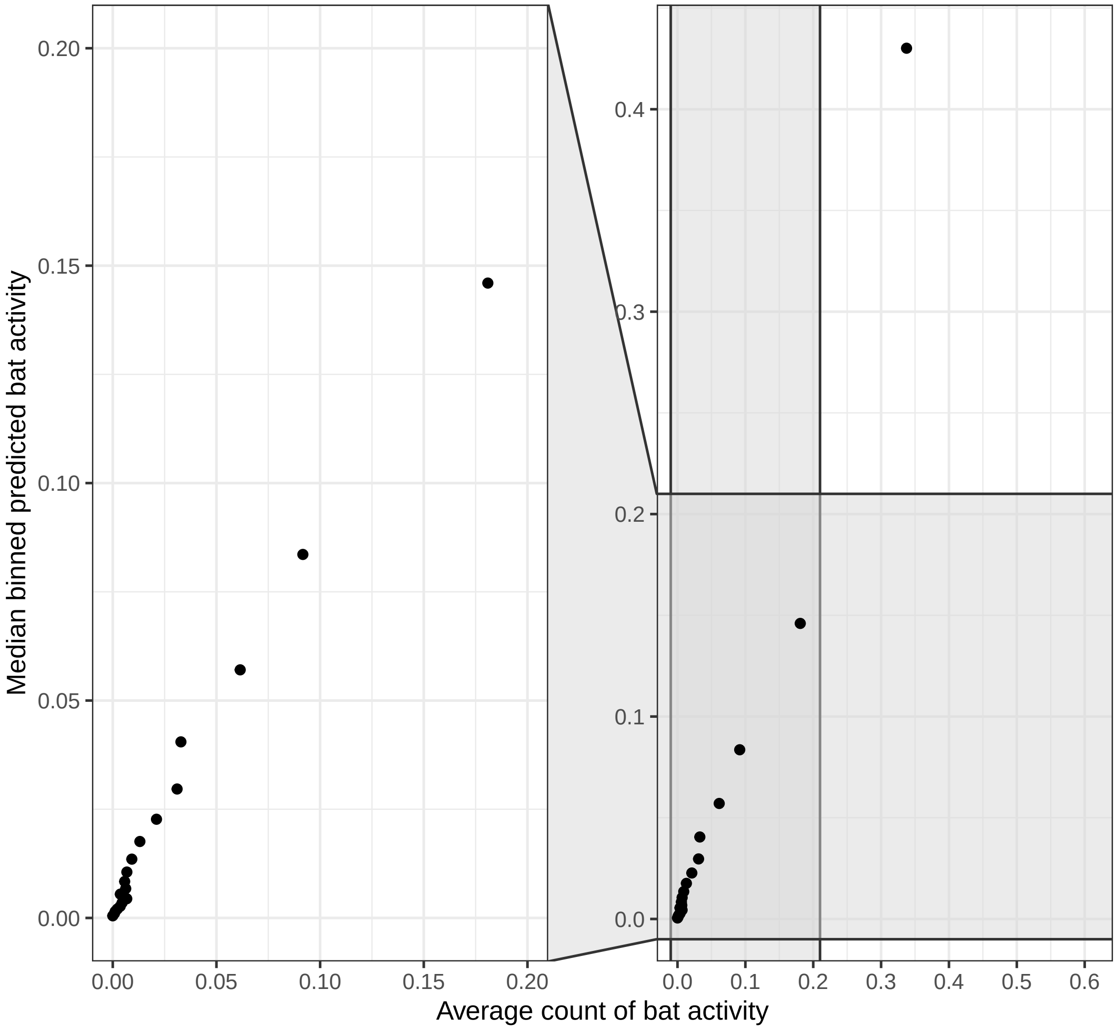

Figure 4.22: Plot of the nightly-level binomial model-based predicted bat activity compared to the observed proportion of bat calls. The R^2 for the model was 0.36.

4.4 Hourly models

4.4.1 Number of bat calls

As above, the hourly number of bat calls per ABM location was assumed to follow a Tweedie distribution. Table 4.8 shows the results of the GLMM which includes all environmental parameters. The model suggests a strong positive effect of sampling period, particularly periods 3 and 4, indicating temporal variation in bat activity across the periods (Figure 4.23). Note that the effect of sampling period is in relation to the reference category (period 1). Once again wind speed, distance to tracks and rivers had negative effects on the number of bat calls. Wind speed and distance to track had a weak effect and distance to river had a strong effect. Temperature and vegetation height had a positive effect that was moderately strong for both. The random effect also showed substantial variability in the response variable between ABMs (SD = 1.63). A strong quadratic effect was estimated between bat call counts and number of hours from sunset, with counts estimated to increase until approximately 5-6 hours after sunset, then decrease thereafter. Bat counts also had a strong negative relationship with the presence of rain, and a strong positive association with northerly winds. Figure 4.24 shows model predictions for each variable holding all other variables constant at their mean value.

Figure 4.25 shows that the model is fairly accurate at predicting counts of bat calls when observed calls were low which represents the vast majority of the data. The model overestimates when higher values of calls per hour are present in the observed data, which occurred infrequently.

Table 4.8: Estimated fixed-effect generalised linear mixed model coefficients fitted to the number of bat calls per hour. Blue p-values are <0.05.

Term	Est	SE	95% CI	t-value	p-value
(Intercept)	-19.53	2.26	[-23.957, -15.105]	-8.65	<0.01
WindSpeed (m/s)	-0.09	0.04	[-0.157, -0.013]	-2.30	0.021
Temp (°C)	0.26	0.03	[0.203, 0.309]	9.50	<0.01
VegHeightMax (m)	0.13	0.04	[0.048, 0.215]	3.09	0.002
DistanceTrack (100m)	-0.14	0.04	[-0.218, -0.051]	-3.15	0.002
DistancePond (100m)	0.04	0.04	[-0.026, 0.117]	1.24	0.215
DistanceRiver (100m)	-0.46	0.18	[-0.817, -0.093]	-2.47	0.014
Period[2]	-1.17	0.32	[-1.789, -0.54]	-3.66	<0.01
Period[3]	1.70	0.24	[1.231, 2.16]	7.15	<0.01
Period[4]	1.71	0.25	[1.228, 2.195]	6.94	<0.01
Direction(Sin)	0.04	0.12	[-0.192, 0.27]	0.34	0.738
Direction(Cos)	0.41	0.15	[0.108, 0.703]	2.67	0.008
HoursSinceSunset	1.05	0.10	[0.86, 1.245]	10.72	<0.01
HoursSinceSunset quadratic	-0.09	0.01	[-0.107, -0.076]	-11.56	<0.01
Elevation (m)	0.02	0.00	[0.006, 0.025]	3.32	0.001
Rainfall present	-0.96	0.30	[-1.543, -0.378]	-3.23	0.001

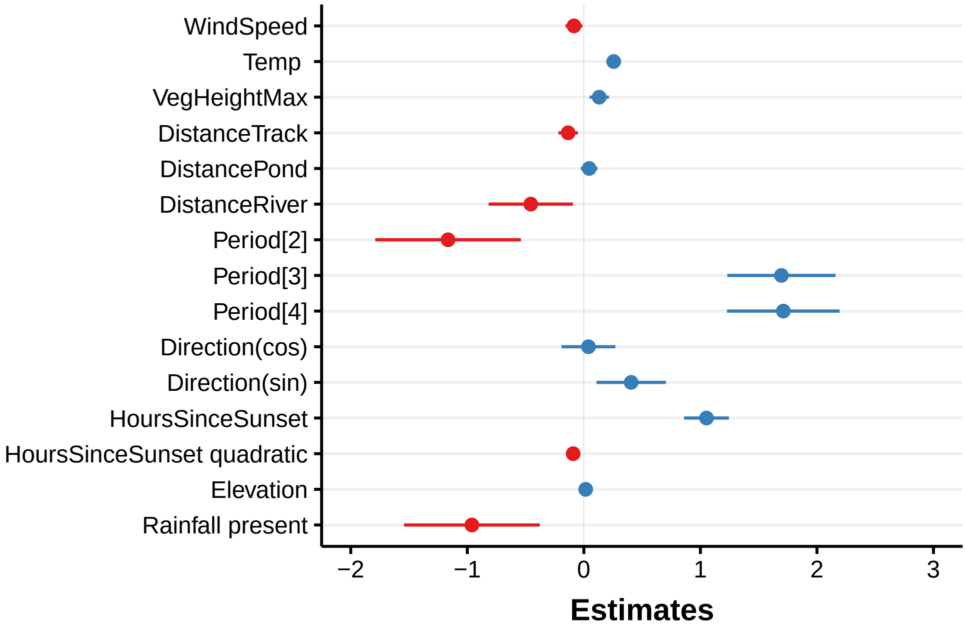

Figure 4.23: Plot of the coefficients for predictor variables in the generalised linear mixed model for the total number of bat calls per hour at each ABM. Positive coefficients (blue) indicate a positive association with the response variable, while negative coefficients (red) suggest a negative association. The horizontal error bars represent 95% confidence intervals.

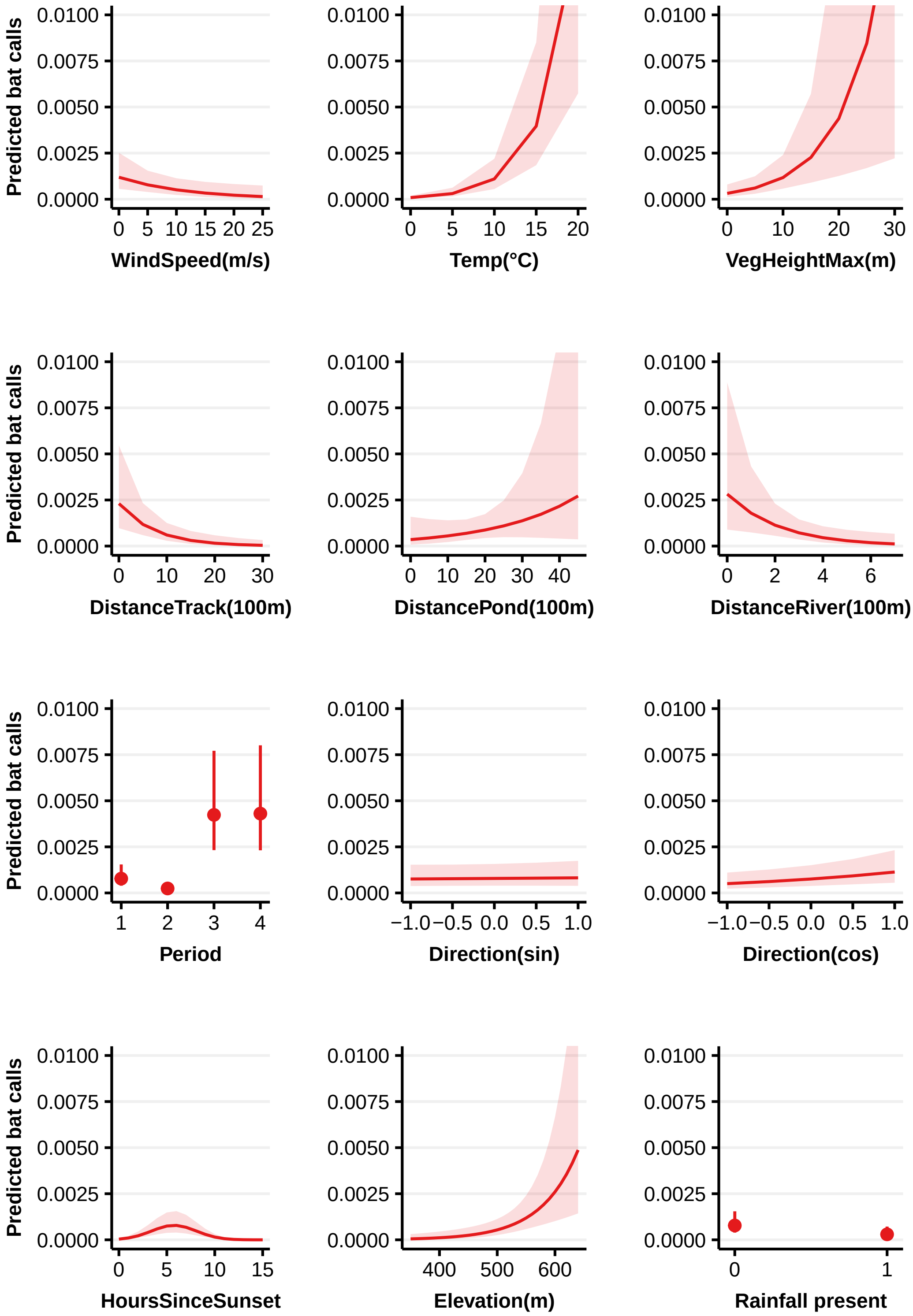

Figure 4.24: Plot of the estimated marginal effects for predictor variables in the generalised linear mixed model of the hourly number of bat calls each ABM. The plot represents the predicted average number of bat calls holding all other variables constant at the mean. The red shaded area indicates the 95% confidence interval.

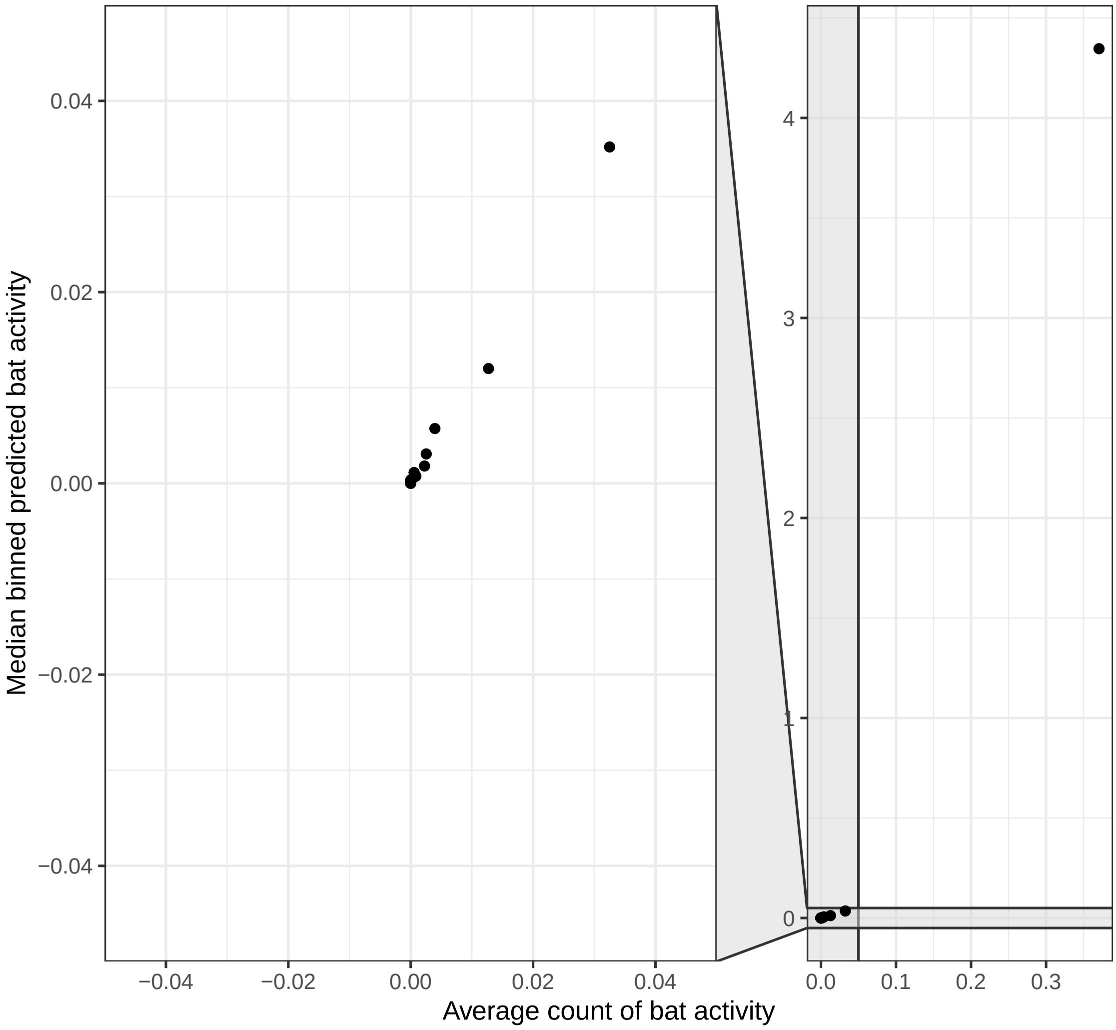

Figure 4.25: Plot of the hourly-level Tweedie model-based predicted number of bat calls compared to the observed number of bat calls. The R^2 for the model was 0.42. The left section of the figure zooms in on the highlighted section of the right to provide detail on the lower values in the figure.

4.4.2 Bat call presence/absence

As above, the presence/absence of bat calls each hour per ABM location was assumed to follow a Bernoulli distribution. Table 4.9 shows the results of the GLM. Again, the results were generally consistent with the Tweedie model at the same temporal scale, and with both models across all temporal scales. The model suggests a strong, positive relationship between the presence of bat calls and sampling period, particularly period 3 and 4, indicating temporal variation in bat presence across the periods. Note that the effect of period is relative to the reference period (period 1). Wind speed, distance to tracks and distance to river had negative effects where the relationship was estimated to be weak for wind speed and distance to track, but strong for distance to river. As in the hourly Tweedie model, temperature and vegetation height had a positive effect that was moderately strong for both, and evidence of a strong quadratic relationship with hours since sunset. Bat call presence was estimated to increase until approximately 5-6 hours after sunset, and then decrease. Lastly, the presence of bat calls had a strong negative relationship with the presence of rain and a strong positive relationship with easterly and northerly winds. Figure 4.24 shows predicted model predictions for each variable, while holding all other variables constant at their mean value and the random effect also showed substantial variability in the response variable between ABMs (SD = 1.63).

Figure 4.28 shows very similar trends to the other figures where the model does is fairly accurate at predicting bat presence when the proportion of observed calls were low, but the model overestimates in the more infrequent occasions that calls were proportionately high.

Table 4.9: Estimated fixed-effect generalised linear mixed model coefficients fitted to the presense of bat calls per hour. Blue p-values are <0.05.

Term	Est	SE	95% CI	t-value	p-value
(Intercept)	-17.12	1.62	[-20.3, -13.932]	-10.54	<0.01
WindSpeed (m/s)	-0.10	0.03	[-0.155, -0.038]	-3.24	0.001
Temp (°C)	0.20	0.02	[0.154, 0.237]	9.23	<0.01
VegHeightMax (m)	0.08	0.03	[0.024, 0.133]	2.81	0.005
DistanceTrack (100m)	-0.09	0.03	[-0.151, -0.037]	-3.24	0.001
DistancePond (100m)	0.02	0.03	[-0.03, 0.066]	0.73	0.463
DistanceRiver (100m)	-0.37	0.12	[-0.616, -0.128]	-2.99	0.003
Period[2]	-0.41	0.30	[-1.005, 0.183]	-1.36	0.175
Period[3]	1.99	0.23	[1.535, 2.442]	8.59	<0.01
Period[4]	1.55	0.24	[1.067, 2.029]	6.31	<0.01
Direction(Sin)	0.34	0.09	[0.16, 0.52]	3.71	<0.01
Direction(Cos)	0.26	0.12	[0.032, 0.492]	2.23	0.026
HoursSinceSunset	0.78	0.08	[0.631, 0.93]	10.23	<0.01
HoursSinceSunset quadratic	-0.07	0.01	[-0.083, -0.058]	-10.75	<0.01
Elevation (m)	0.01	0.00	[0.007, 0.021]	4.20	<0.01
Rainfall present	-0.82	0.29	[-1.38, -0.253]	-2.84	0.004

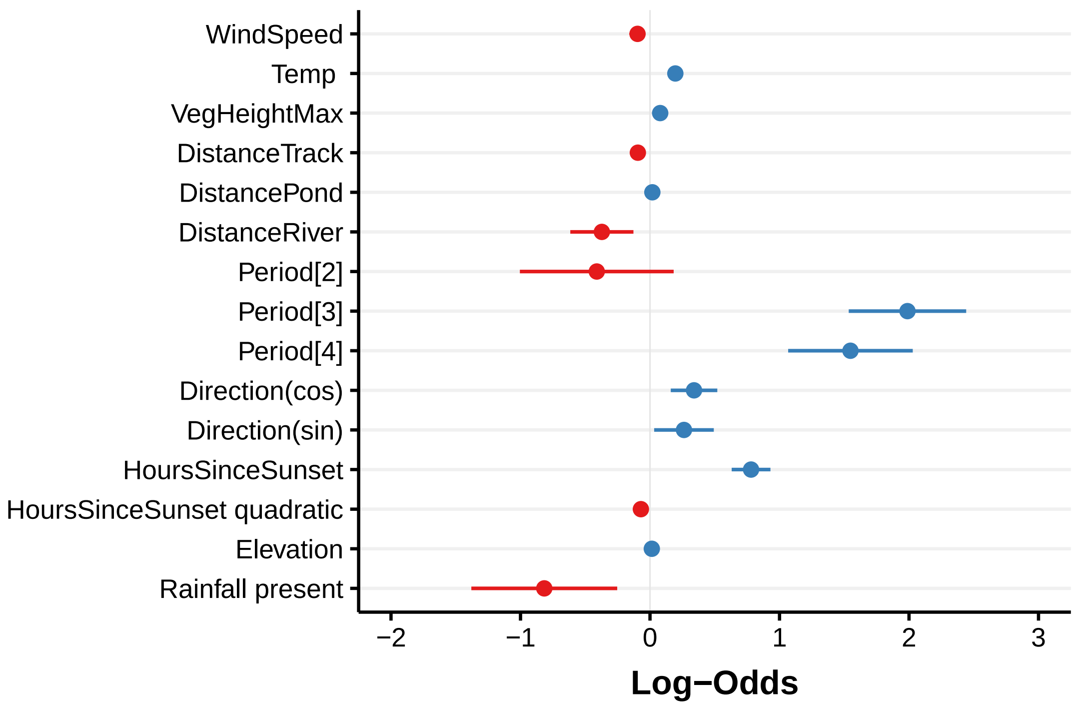

Figure 4.26: Plot of the log-odds for predictor variables in the generalised linear mixed model for the presence of bats per hour at each ABM. Positive coefficients (blue) indicate a positive association with the response variable, while negative coefficients (red) suggest a negative association. The horizontal error bars represent 95% confidence intervals.

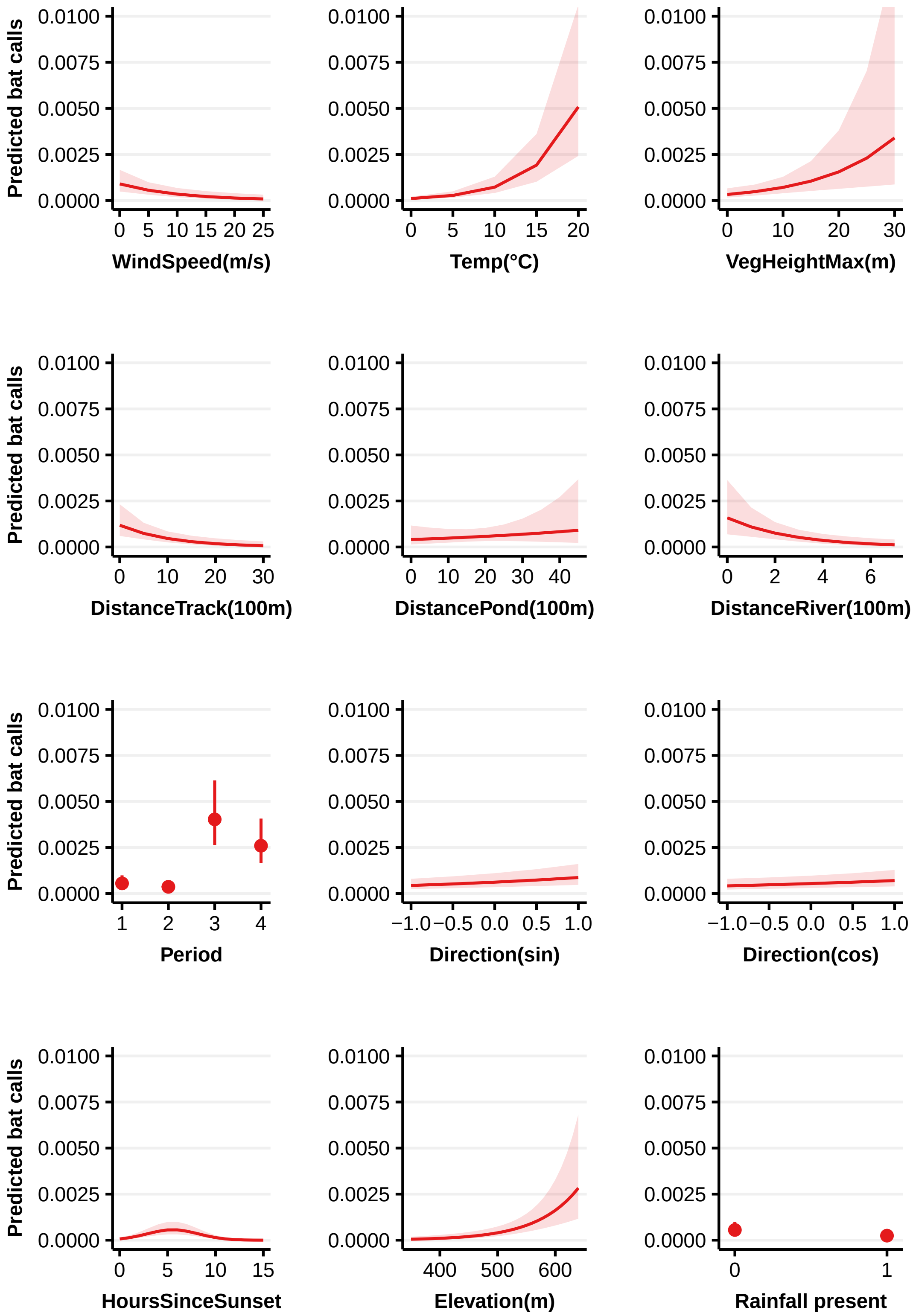

Figure 4.27: Eestimated marginal effect plot for predictor variables in the generalized linear mixed model of the presence of bat calls on the hourly scale. The plot represents the predicted average probability of bat calls being present, holding all other variables constant at the mean. The red shaded area indicates the 95% confidence interval. Note the y-axis does not extend from 0-1.

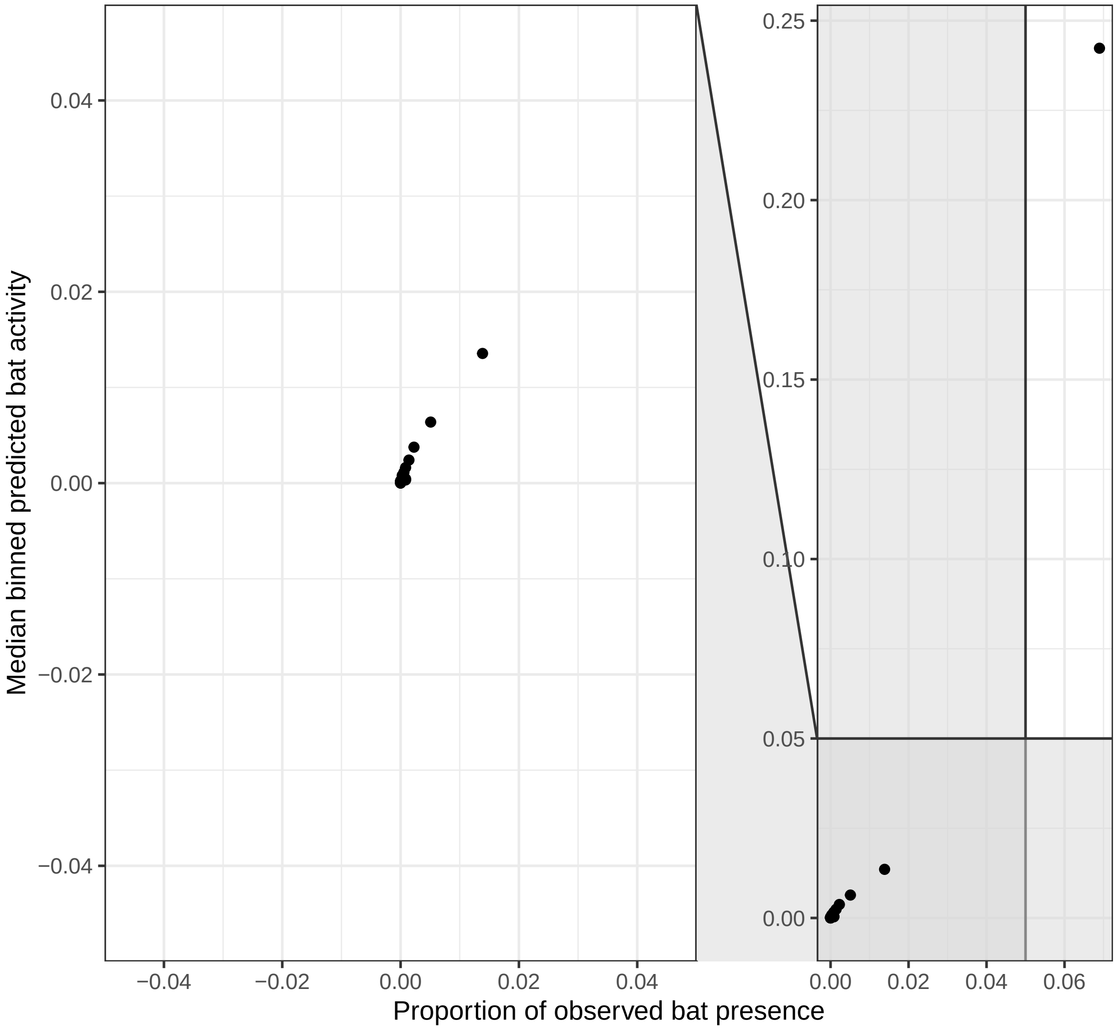

Figure 4.28: Plot of the hourly-level binomial model-based predicted bat activity compared to the observed proportion of bat calls. The R^2 for the model was 0.51 The left section of the figure zooms in on the highlighted section of the right to provide detail on the lower values in the figure.

4.5 Patterns across scales

Generally, in terms of the direction (i.e., positive or negative) and relative size of the effects, the results from the models of bat call counts were consistent across all temporal scales, as were the models of bat call presence. Moreover, the results from the models of bat call counts were consistent with the models of bat call presence within each spatial scale. Because the models are at different temporal scales and use different metrics, some differences in effect size and uncertainty surrounding model estimates are to be expected. Occasionally, different covariates would be statistically significant across different models, but it should be emphasised that statistical significance is different than practical significance. An effect may be statistically significant, but have little practical influence on bat activity, and vice-versa. Evaluation of the covariate effect size confidence interval limits can be informative as they account for the uncertainty in the effect size due to variation in the data (narrow confidence intervals have less uncertainty). Comparisons of all estimated effect sizes across the three temporal scales, including their interpretations on the real scale (in terms of percent change), are given in Tables 4.10 and 4.11. Note the percent change values for the hours since sunset effect should be ignored given the quadratic relationship that was modelled.

However, direct comparison of effect sizes for continuous-valued covariates to evaluate relative importance does require consideration of the differences in covariate scale (e.g., m/s vs 100 m). To aid such comparisons, the effects of continuous-valued covariates have been reinterpreted in terms of the change in the covariate value that would result in a halving of bat activity. These reinterpretations are presented in the appendix (Tables D.1 and D.2).

Table 4.10: Comparison of fixed-effect generalised linear mixed model coefficients for all models of bat call count. The percent change column represents the percentage change in the expected number of bat calls associated with a one-unit increase in the predictor variable. The percentage change for hours since sunset effects should be ignored given the quadratic relationship that was modelled.

	Hourly				Nightly				Session			
Term	Est	SE	95% CI	% Change	Est	SE	95% CI	% Change	Est	SE	95% CI	% Change
(Intercept)	-19.53	2.26	[-23.957, -15.105]		-11.95	2.17	[-16.2, -7.71]		-7.91	2.14	[-12.11, -3.7]	
WindSpeed (m/s)	-0.09	0.04	[-0.157, -0.013]	-8.15	-0.16	0.05	[-0.25, -0.06]	-14.79	-0.56	0.18	[-0.91, -0.21]	-42.88
Temp (°C)	0.26	0.03	[0.203, 0.309]	29.18								
VegHeightMax (m)	0.13	0.04	[0.048, 0.215]	14.11	0.12	0.04	[0.04, 0.2]	12.75	0.09	0.04	[0.01, 0.16]	9.42
DistanceTrack (100m)	-0.14	0.04	[-0.218, -0.051]	-12.63	-0.12	0.04	[-0.2, -0.04]	-11.31	-0.10	0.04	[-0.18, -0.01]	-9.52
DistancePond (100m)	0.04	0.04	[-0.026, 0.117]	4.60	0.03	0.04	[-0.04, 0.1]	3.05	0.04	0.04	[-0.03, 0.11]	4.08
DistanceRiver (100m)	-0.46	0.18	[-0.817, -0.093]	-36.56	-0.49	0.18	[-0.84, -0.14]	-38.74	-0.44	0.17	[-0.78, -0.11]	-35.60
Period[2]	-1.17	0.32	[-1.789, -0.54]	-68.81	-0.25	0.36	[-0.95, 0.46]	-22.12	0.15	0.47	[-0.77, 1.08]	16.18
Period[3]	1.70	0.24	[1.231, 2.16]	444.66	2.37	0.28	[1.81, 2.92]	969.74	2.40	0.35	[1.72, 3.09]	1002.32
Period[4]	1.71	0.25	[1.228, 2.195]	454.00	1.98	0.29	[1.4, 2.56]	624.27	1.95	0.36	[1.24, 2.66]	602.87
Direction(Sin)	0.04	0.12	[-0.192, 0.27]	3.98								
Direction(Cos)	0.41	0.15	[0.108, 0.703]	50.08								
HoursSinceSunset	1.05	0.10	[0.86, 1.245]	186.34								
HoursSinceSunset quadratic	-0.09	0.01	[-0.107, -0.076]	-8.79								
Elevation (m)	0.02	0.00	[0.006, 0.025]	1.61	0.02	0.00	[0.01, 0.02]	2.02	0.02	0.00	[0.01, 0.03]	2.02
Rainfall present	-0.96	0.30	[-1.543, -0.378]	-61.75								

Table 4.11: Comparison of fixed-effect generalised linear mixed model coefficients for all models of bat call presence. The percent change column represents the percentage change in the odds of the presence of bat calls for each unit increase in the predictor variable. The percentage change for hours since sunset effects should be ignored given the quadratic relationship that was modelled.

	Hourly				Nightly				Session			
Term	Est	SE	95% CI	% Change	Est	SE	95% CI	% Change	Est	SE	95% CI	% Change
(Intercept)	-17.12	1.62	[-20.3, -13.932]		-10.63	1.50	[-13.58, -7.68]		-8.14	1.61	[-11.46, -5.12]	
WindSpeed (m/s)	-0.10	0.03	[-0.155, -0.038]	-9.15	-0.19	0.04	[-0.25, -0.12]	-17.30	-0.17	0.13	[-0.43, 0.08]	-15.63
Temp (°C)	0.20	0.02	[0.154, 0.237]	21.65								
VegHeightMax (m)	0.08	0.03	[0.024, 0.133]	8.22	0.07	0.03	[0.02, 0.12]	7.25	0.10	0.03	[0.04, 0.16]	10.52
DistanceTrack (100m)	-0.09	0.03	[-0.151, -0.037]	-8.97	-0.08	0.03	[-0.14, -0.03]	-7.69	-0.07	0.03	[-0.13, -0.03]	-6.76
DistancePond (100m)	0.02	0.03	[-0.03, 0.066]	1.82	0.01	0.02	[-0.03, 0.06]	1.01	0.01	0.02	[-0.04, 0.05]	1.01
DistanceRiver (100m)	-0.37	0.12	[-0.616, -0.128]	-31.06	-0.34	0.12	[-0.56, -0.11]	-28.82	-0.36	0.12	[-0.6, -0.14]	-30.23
Period[2]	-0.41	0.30	[-1.005, 0.183]	-33.70	0.35	0.33	[-0.3, 1]	41.91	1.01	0.56	[-0.05, 2.15]	174.56
Period[3]	1.99	0.23	[1.535, 2.442]	630.09	2.53	0.27	[2, 3.06]	1155.35	3.22	0.53	[2.25, 4.33]	2402.81
Period[4]	1.55	0.24	[1.067, 2.029]	370.21	1.61	0.29	[1.05, 2.17]	400.28	1.60	0.52	[0.61, 2.68]	395.30
Direction(Sin)	0.34	0.09	[0.16, 0.52]	40.49								
Direction(Cos)	0.26	0.12	[0.032, 0.492]	29.95								
HoursSinceSunset	0.78	0.08	[0.631, 0.93]	118.15								
HoursSinceSunset quadratic	-0.07	0.01	[-0.083, -0.058]	-6.76								
Elevation (m)	0.01	0.00	[0.007, 0.021]	1.41	0.01	0.00	[0.01, 0.02]	1.01	0.01	0.00	[0.01, 0.02]	1.01
Rainfall present	-0.82	0.29	[-1.38, -0.253]	-55.78								

5. Discussion

Based on results that were consistent across multiple models, several variables are likely influencing how bats are using the proposed wind farm site. Tall vegetation is associated with a higher level of bat activity across all models. Bat activity is predicted to be higher in areas that are close to mapped rivers and tracks, though the effect of rivers is stronger than that of tracks. Bat activity is also predicted to increase slightly with rising elevation.

All models highlighted that sampling periods three and four, which took place in March and April, respectively, had significantly more bat activity than periods earlier in the season. Lastly, wind speed was influential in five of the six models, where bat activity is slightly higher at lower wind speeds.

Temperature and wind direction were only assessed in the hourly binomial and Tweedie models. These models suggest that bat activity increases when temperatures rise and when winds are blowing north-easterly.

Results from our models assist in identifying environmental variables influence bat activity, the direction and magnitude of the effect, and model predictions visualising the potential level of bat activity in relation to key environmental variables. Many of the predictor variables in the analysis were static as they were associated with the location of the ABM (e.g., distance to the nearest river or track). We have highlighted two more dynamic variables: temperature and wind speed that were found to influence bat activity (counts and presence absence) in the models. Figures representing the cumulative relationship between bat activity, temperature, and wind speed for nine ABM locations identified by I. Davidson-Watts and G. Kessels are provided in the appendix. These ABMs were identified by bat experts to assist with understanding bat activity at nearby turbine locations.

6. References

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Wickham, H., Averick, M., Bryan, J., Chang, W., McGowan, L., François, R., Grolemund, G., Hayes, A., Henry, L., Hester, J., Kuhn, M., Pedersen, T., Miller, E., Bache, S., Müller, K., Ooms, J., Robinson, D., Seidel, D., Spinu, V., … Yutani, H. (2019). Welcome to the Tidyverse. *Journal of Open Source Software*, *4*(43), 1686. https://doi.org/10.21105/joss.01686

7. Appendix

A Relationship between hourly bat activity and vegetation height

On request, Figure A.1 presents a marginal effect plot of the relationship between hourly bat activity and vegetation height. The information plotted is the same as that in Figure 4.24, with a particular focus on vegetation height and where the y-axis (bat counts) has been log-transformed.

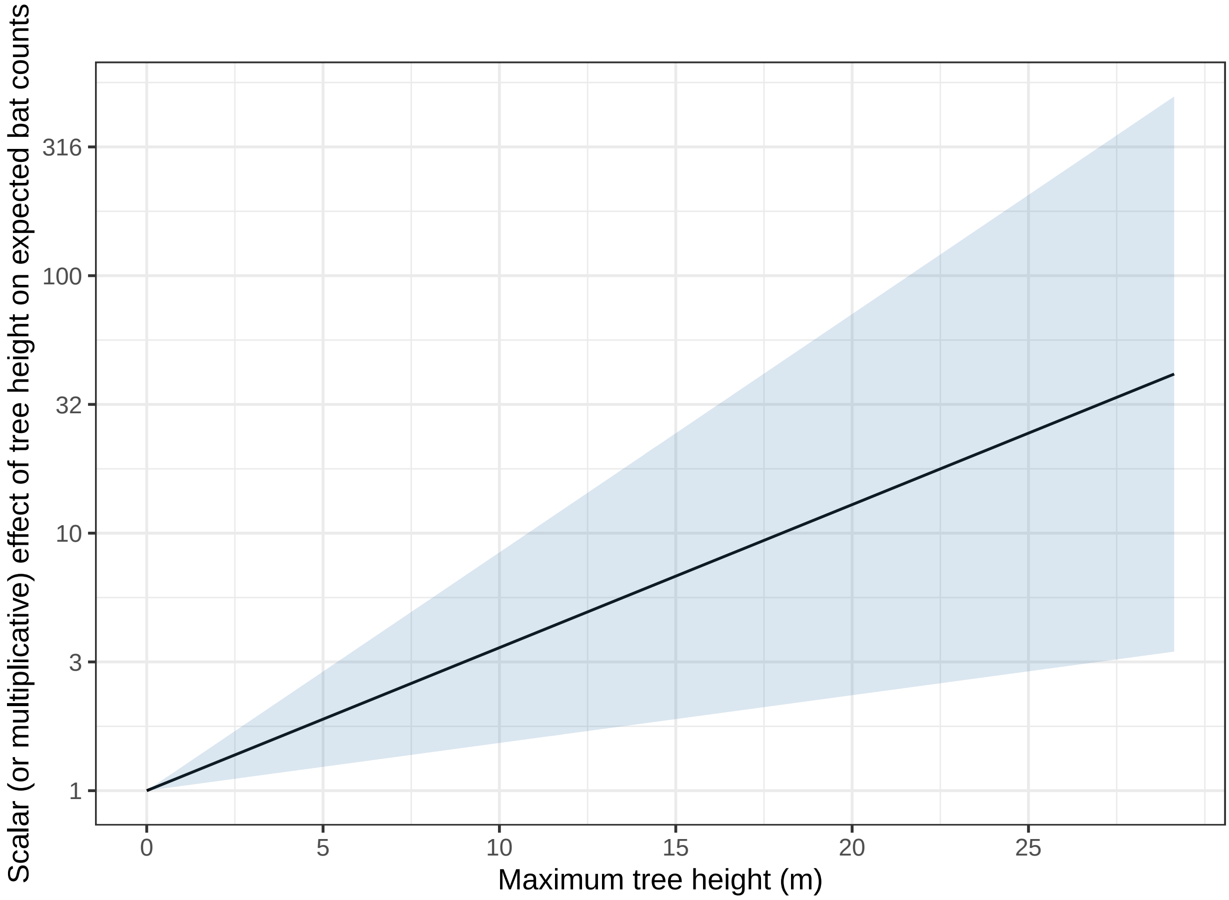

Figure A.1: An effect plot presenting the relationship between bat activity and vegetation height. The scale of the y-axis has been log-transormed. The gray area represents the 95% confidence interval.

B Relationships between hourly bat activity with temperature and wind speed

Six figures were created for nine ABM locations to explore the relationship of bat activity with temperature, and wind speed during the survey periods, resulting in 12 figures per ABM location. These locations were identified by I. Davidson-Watts and G. Kessels.

In all figures, the x-axis represents a bin of temperature or wind speed with a bin width of 0.5. The value on the x-axis represents the upper limit of each bin. For instance, if the x-axis value is 4, it denotes temperatures (°C) or wind speeds (m/s) ranging between 3.5 and 4.0.

Observed bat passes represent the cumulative sum of passes (counts or presence-absence) observed in the raw data within each survey period, at each bin. Predicted bat passes represent the cumulative sum of passes predicted by the model for each bin.

The proportion of observed bat passes represents the proportion of the total number of observations that was observed at each bin for the given period and ABM location. Proportion predicted represents the same calculation but for the data predicted by the model.

The number of running hours represents the number of hours that an ABM was active at the binned value of temperature or wind speed in each survey period, and the proportion of total running hours turns those observations into a proportion.

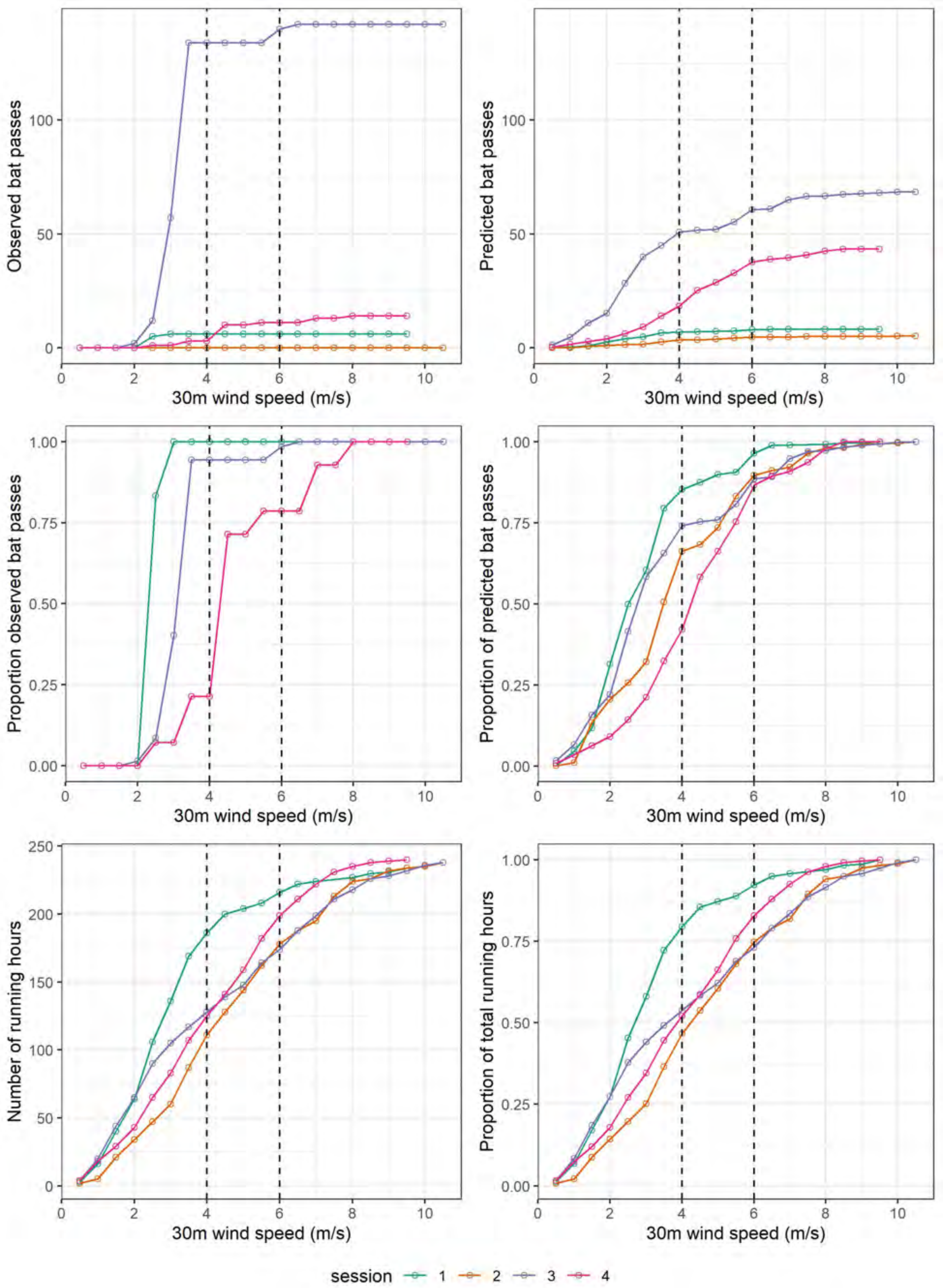

Figure B.2: Relationship between counts of observed and predicted hourly bat passes and wind speed (m/s) from the tweedie model for ABM B52.

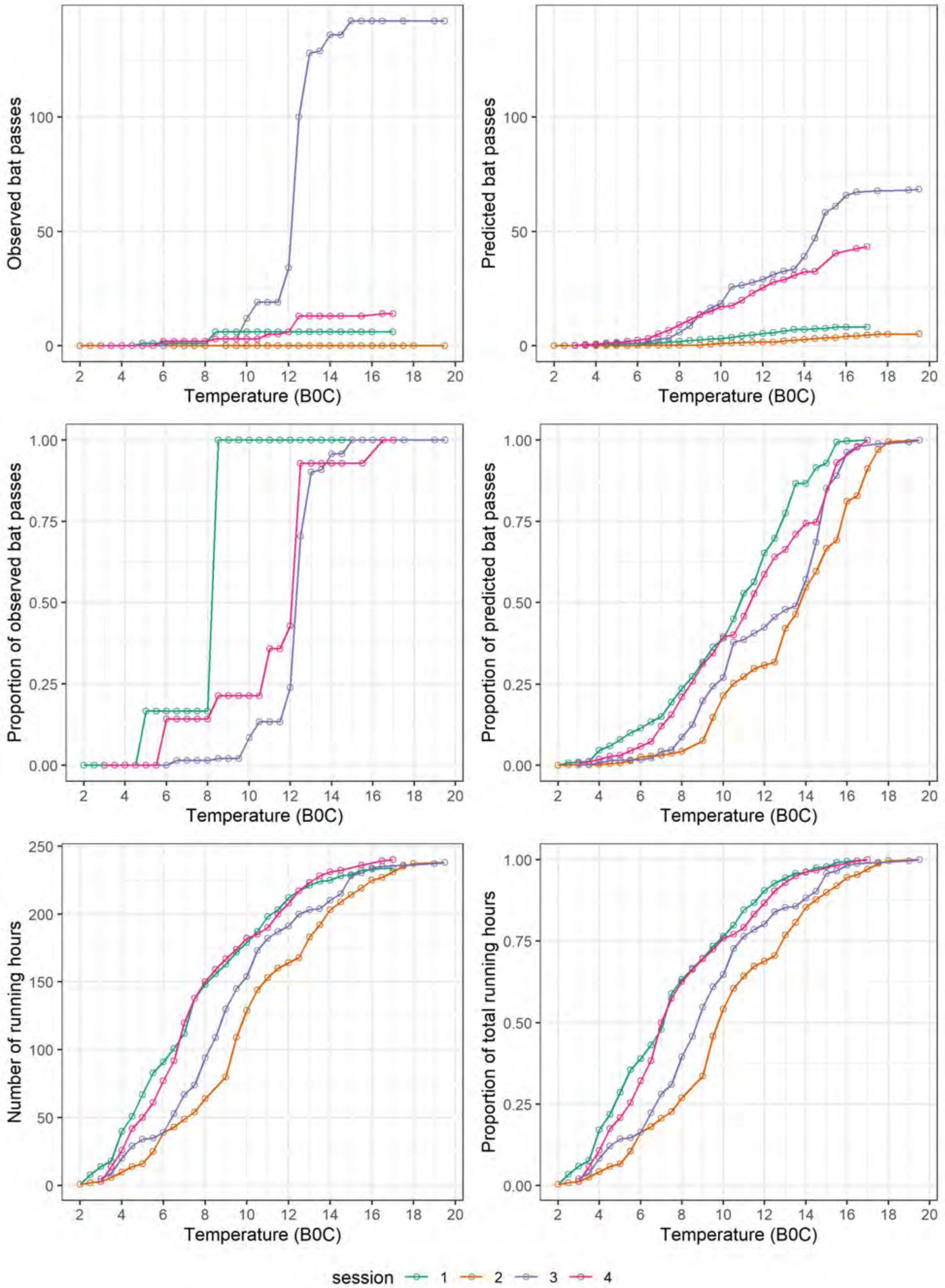

Figure B.3: Relationship between counts of observed and predicted hourly bat passes and temperature (°C) from the tweedie model for ABM B52

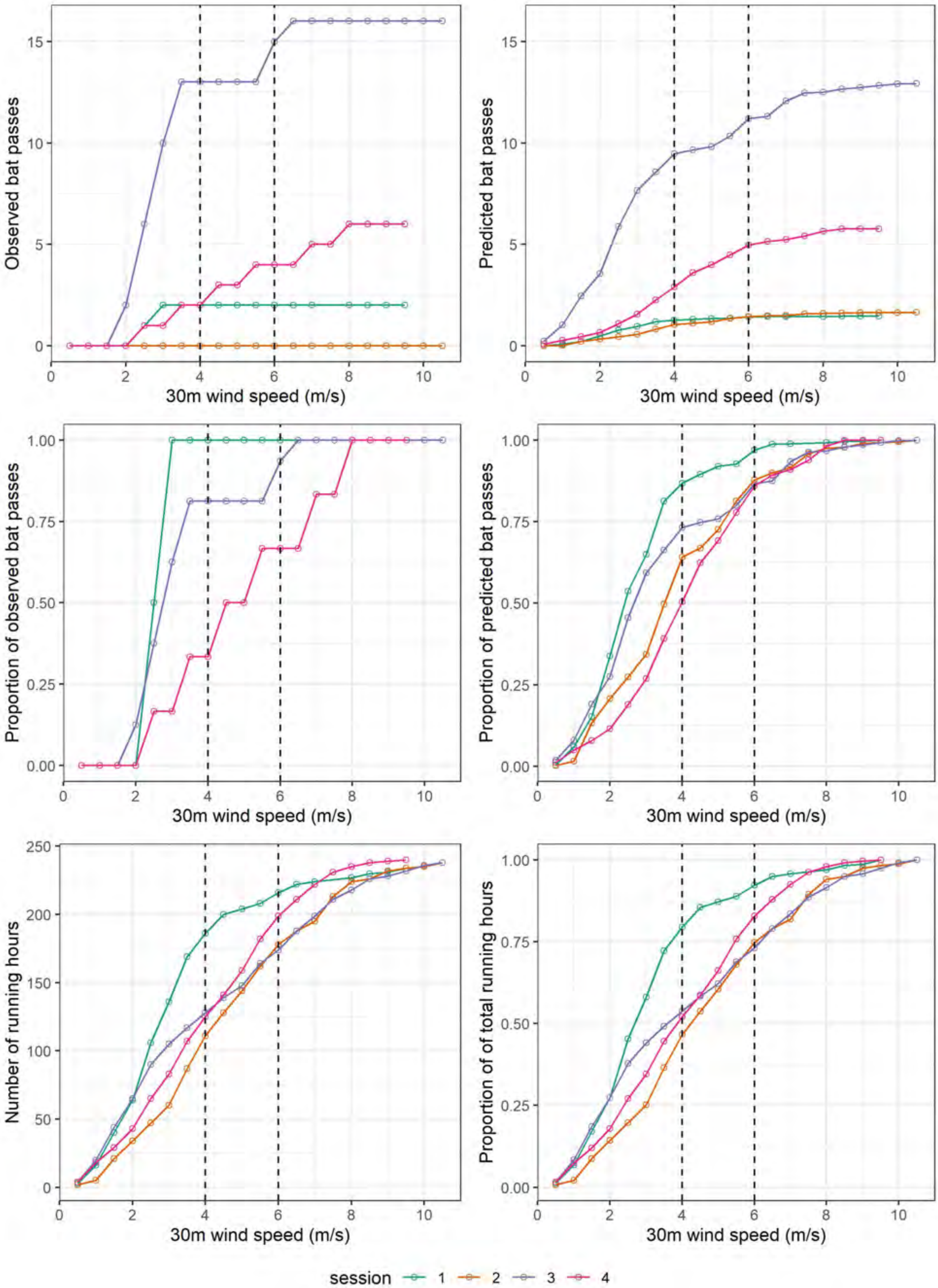

Figure B.4: Relationship between the presence or absence of observed and predicted hourly bat passes and wind speed (m/s) from the binomial model for ABM B52.

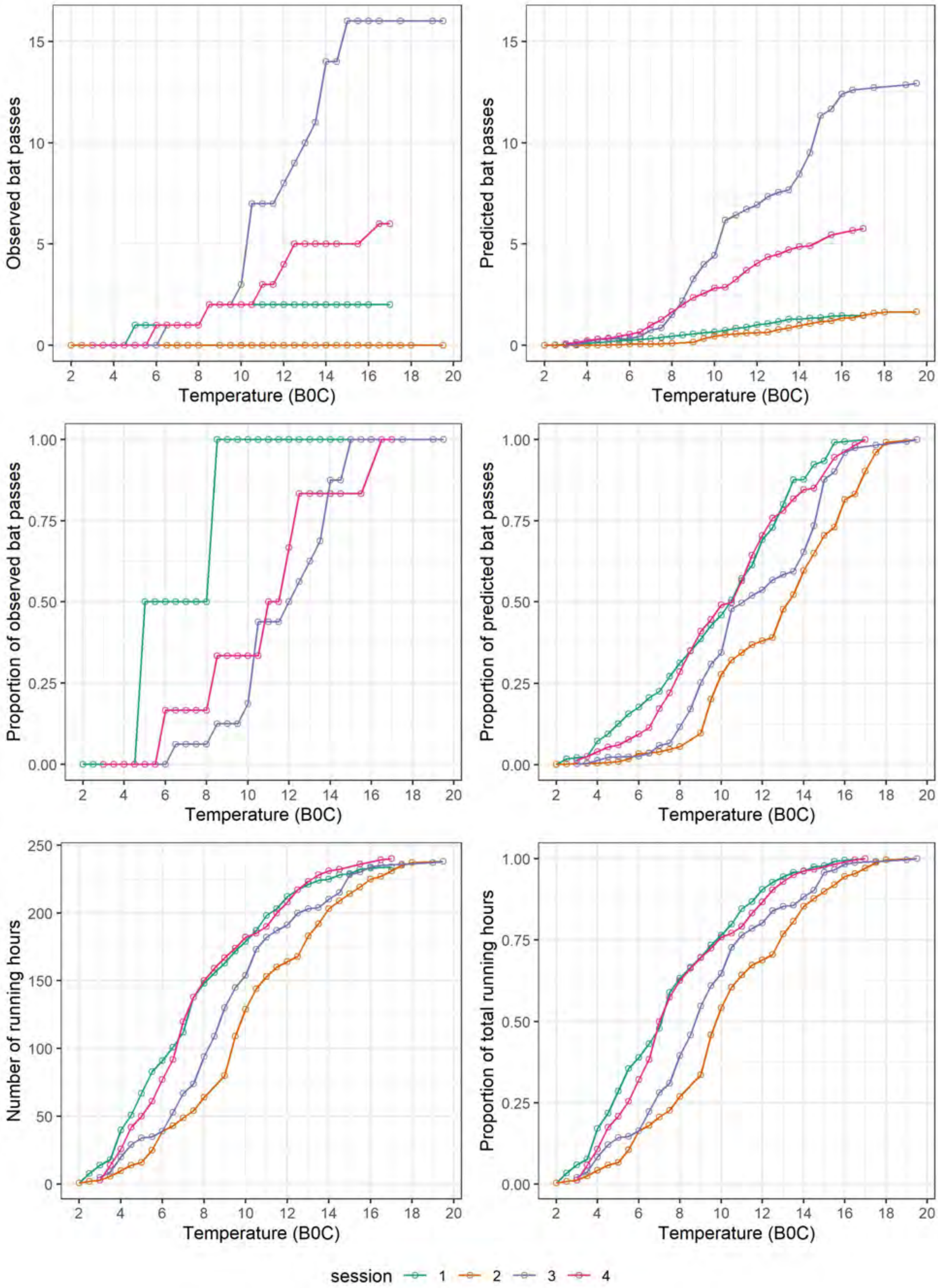

Figure B.5: Relationship between the presence or absence of observed and predicted hourly bat passes and temperature (°C) from the binomial model for ABM B52

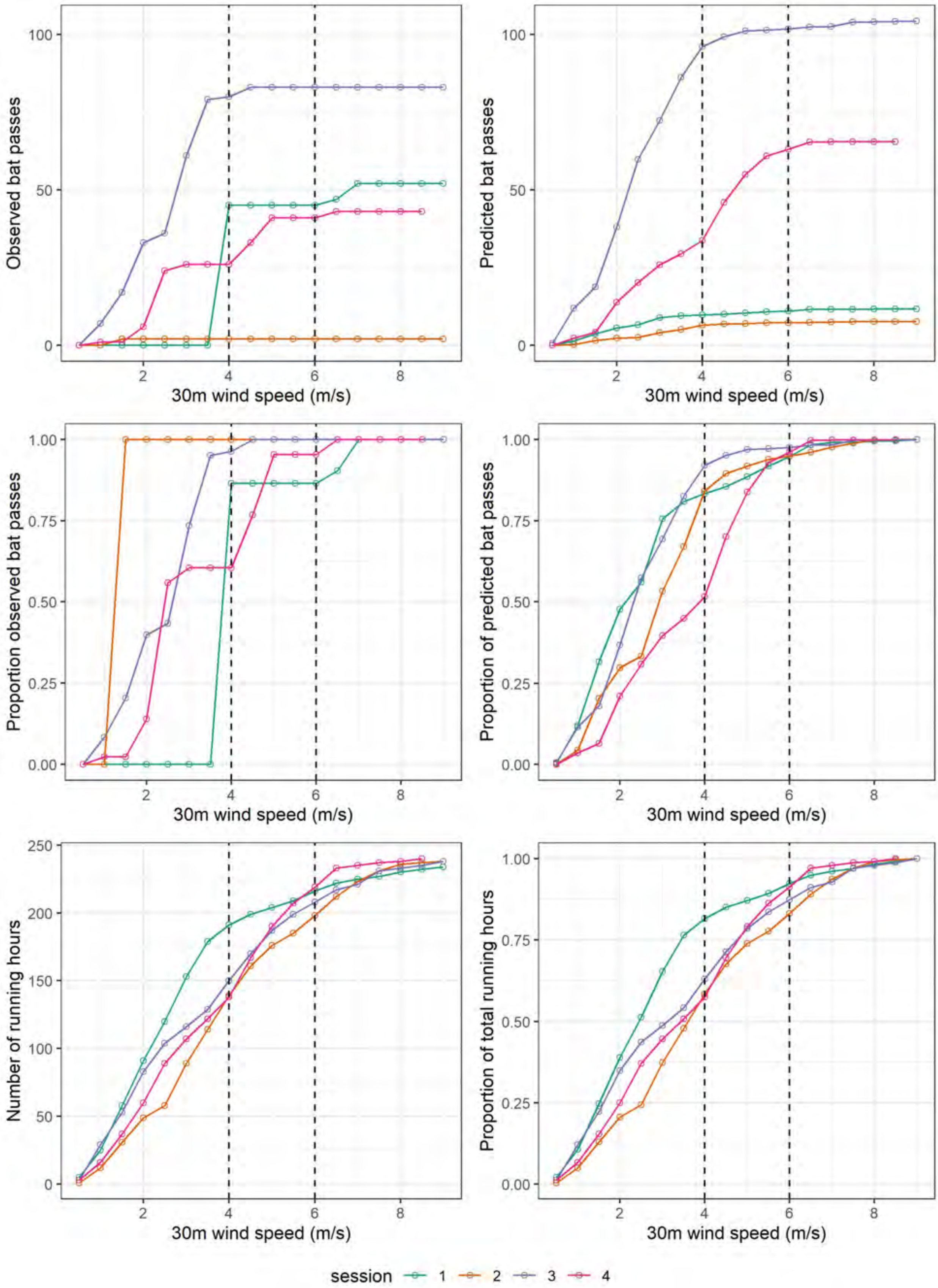

Figure B.6: Relationship between counts of observed and predicted hourly bat passes and wind speed (m/s) from the tweedie model for ABM B58.

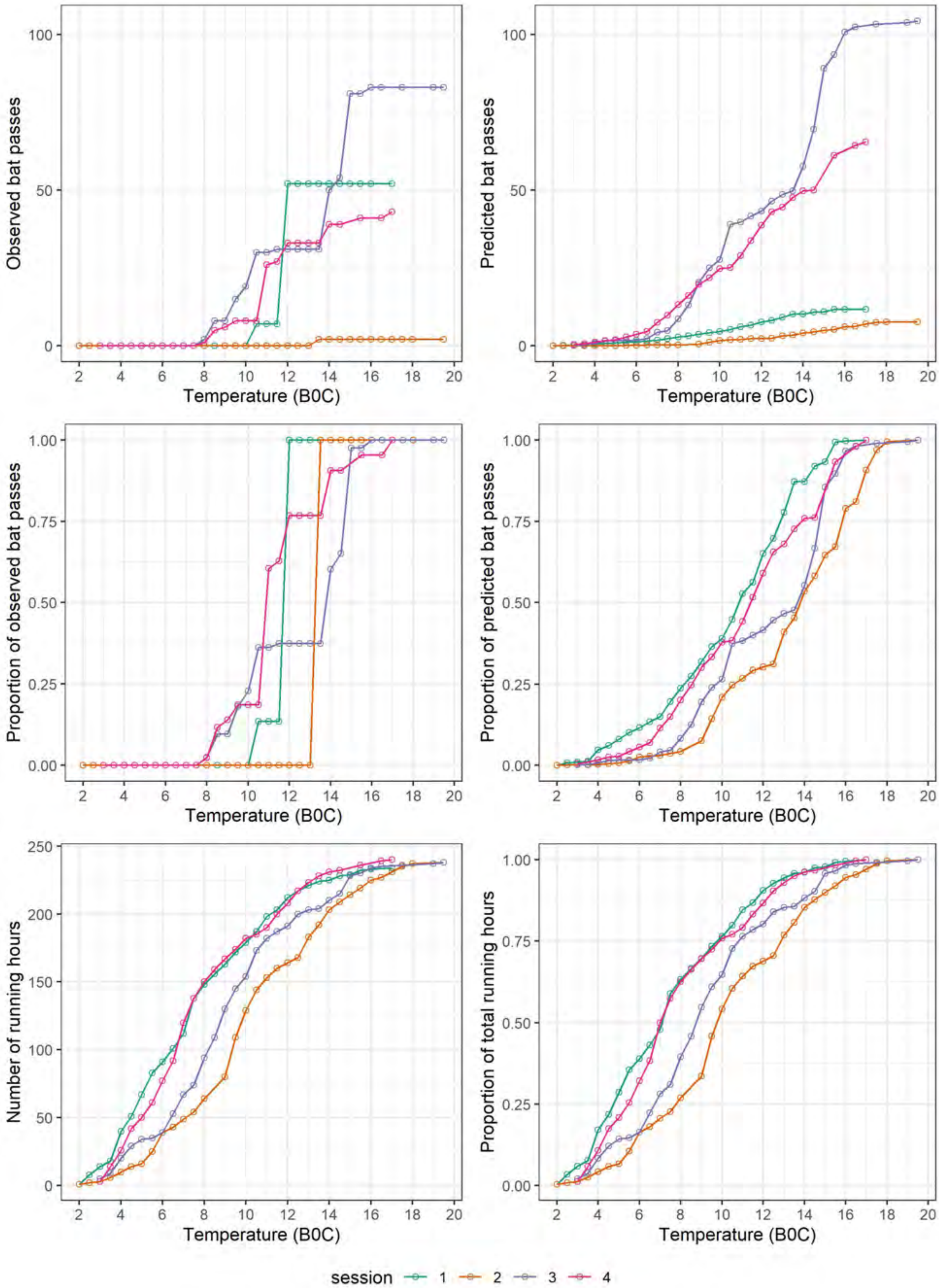

Figure B.7: Relationship between counts of observed and predicted hourly bat passes and temperature (°C) from the tweedie model for ABM B58

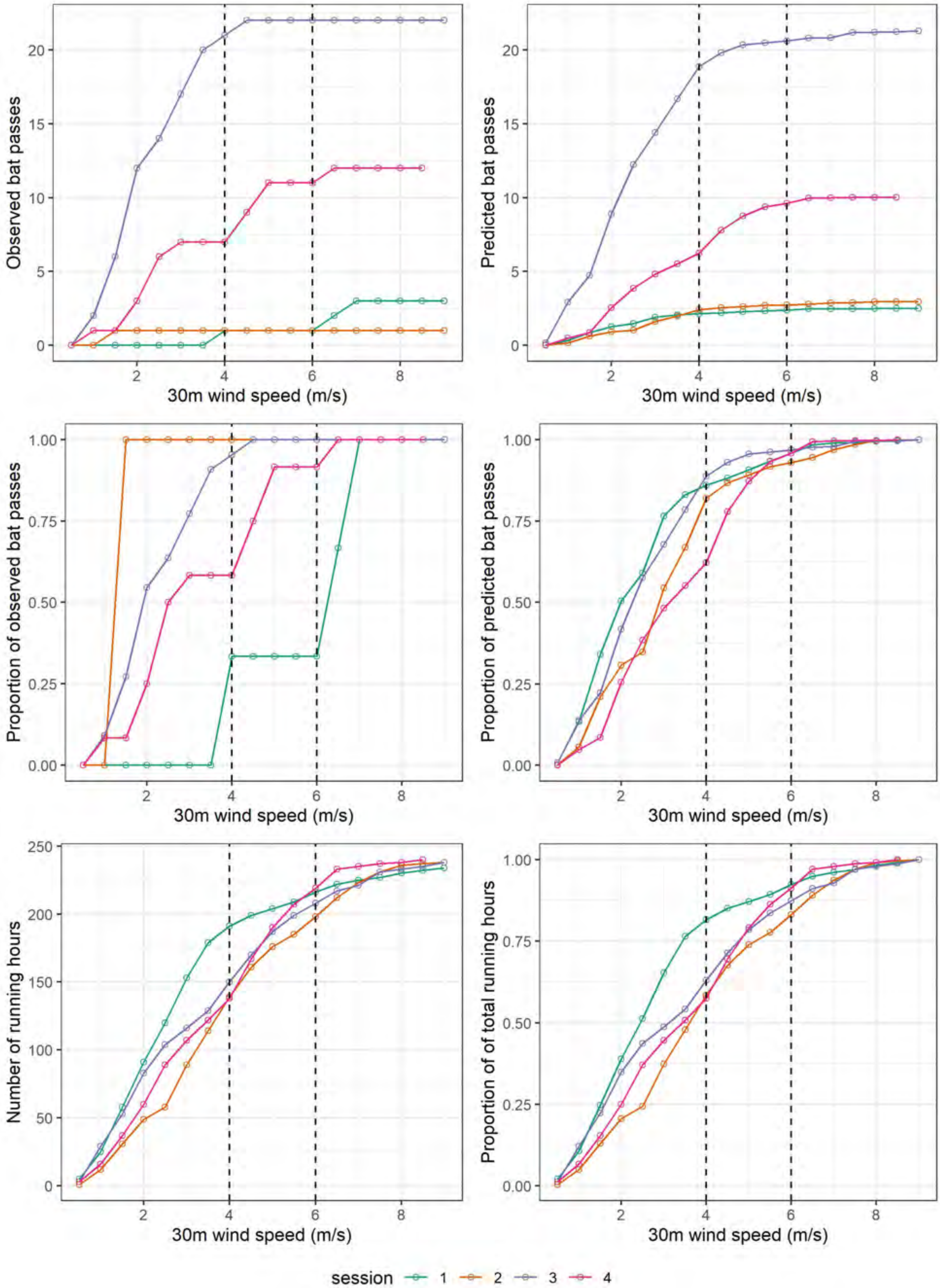

Figure B.8: Relationship between the presence or absence of observed and predicted hourly bat passes and wind speed (m/s) from the binomial model for ABM B58.

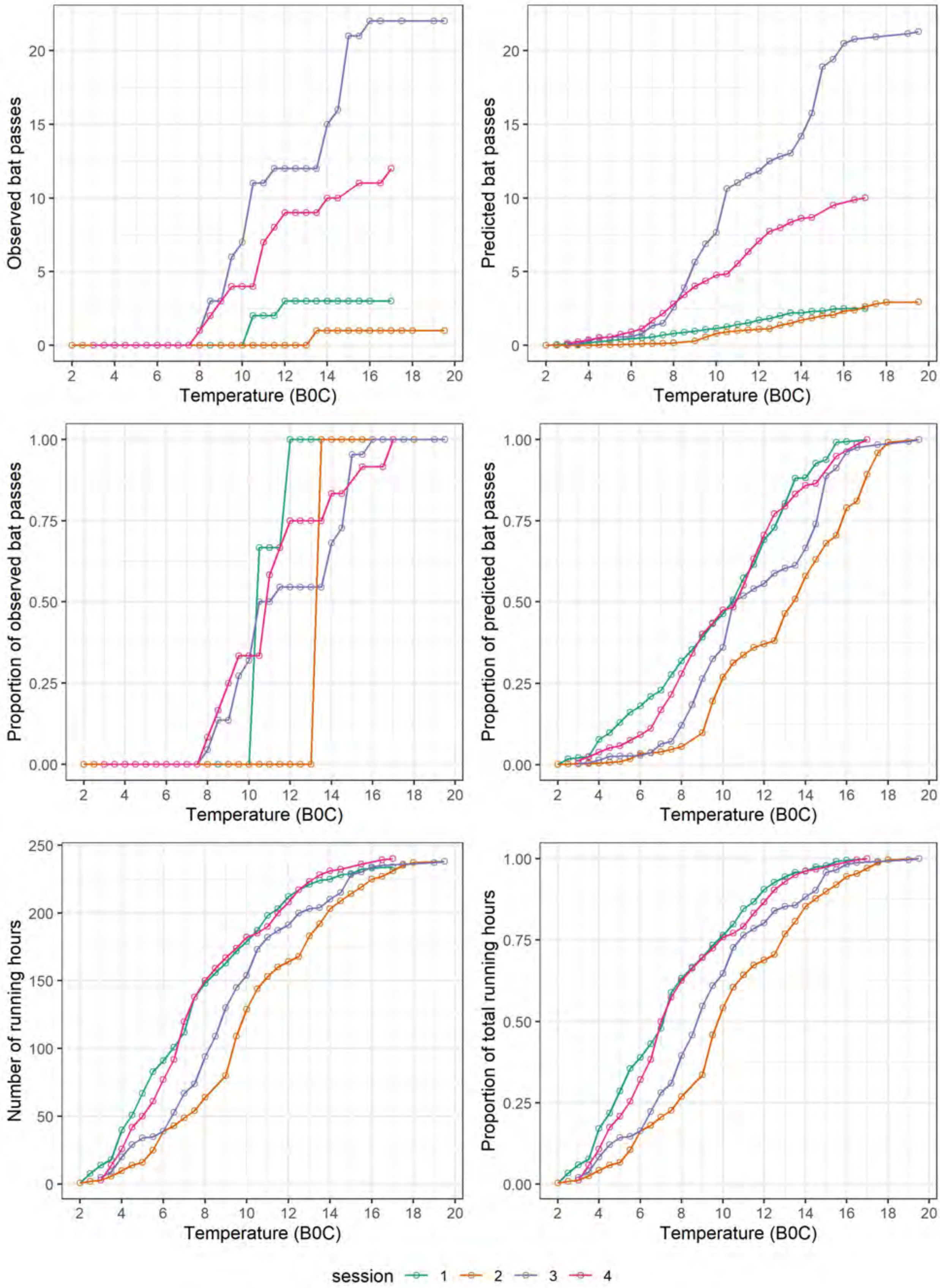

Figure B.9: Relationship between the presence or absence of observed and predicted hourly bat passes and temperature (°C) from the binomial model for ABM B58.

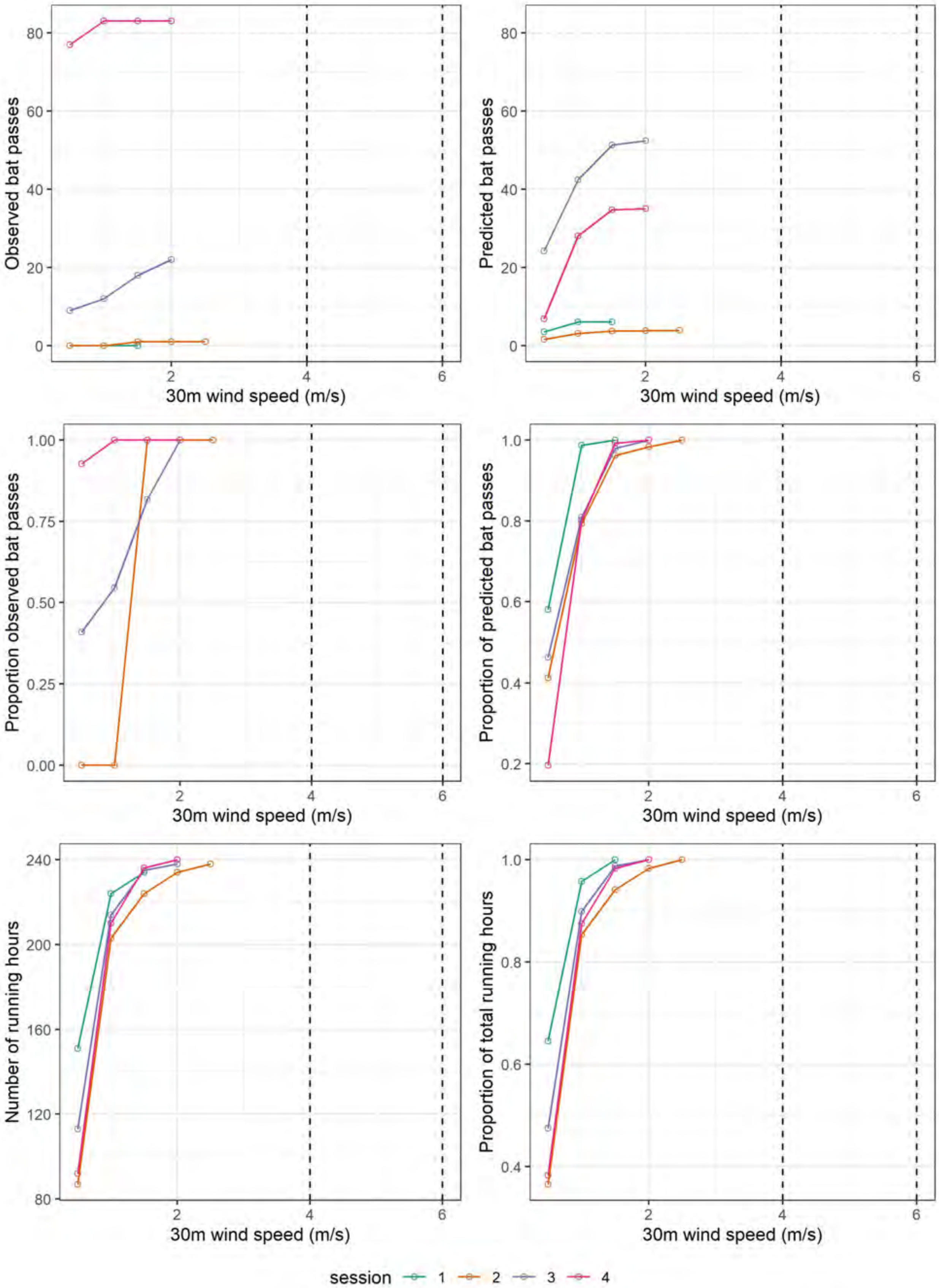

Figure B.10: Relationship between counts of observed and predicted hourly bat passes and wind speed (m/s) from the tweedie model for ABM B64.

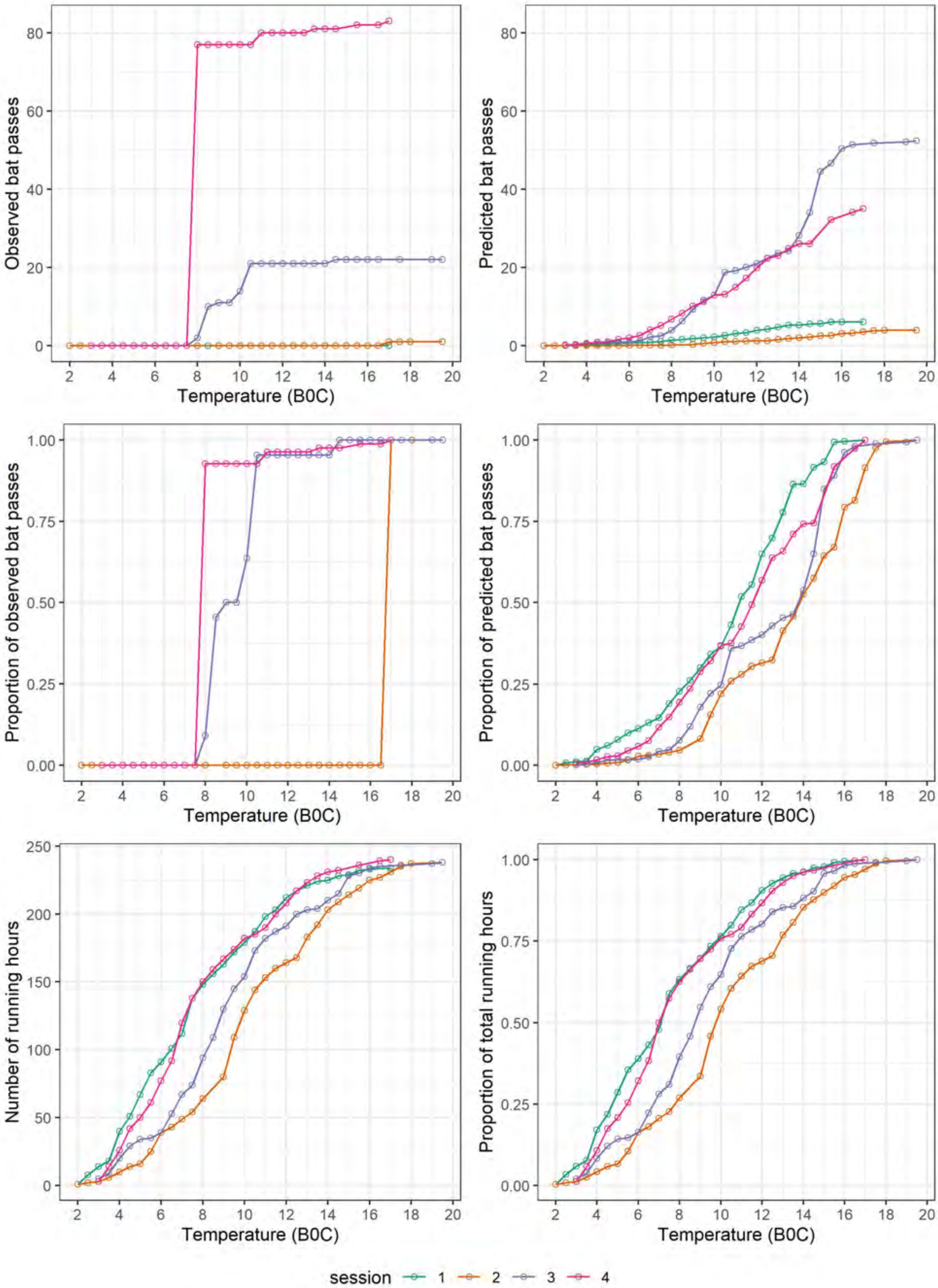

Figure B.11: Relationship between counts of observed and predicted hourly bat passes and temperature (°C) from the tweedie model for ABM B64.

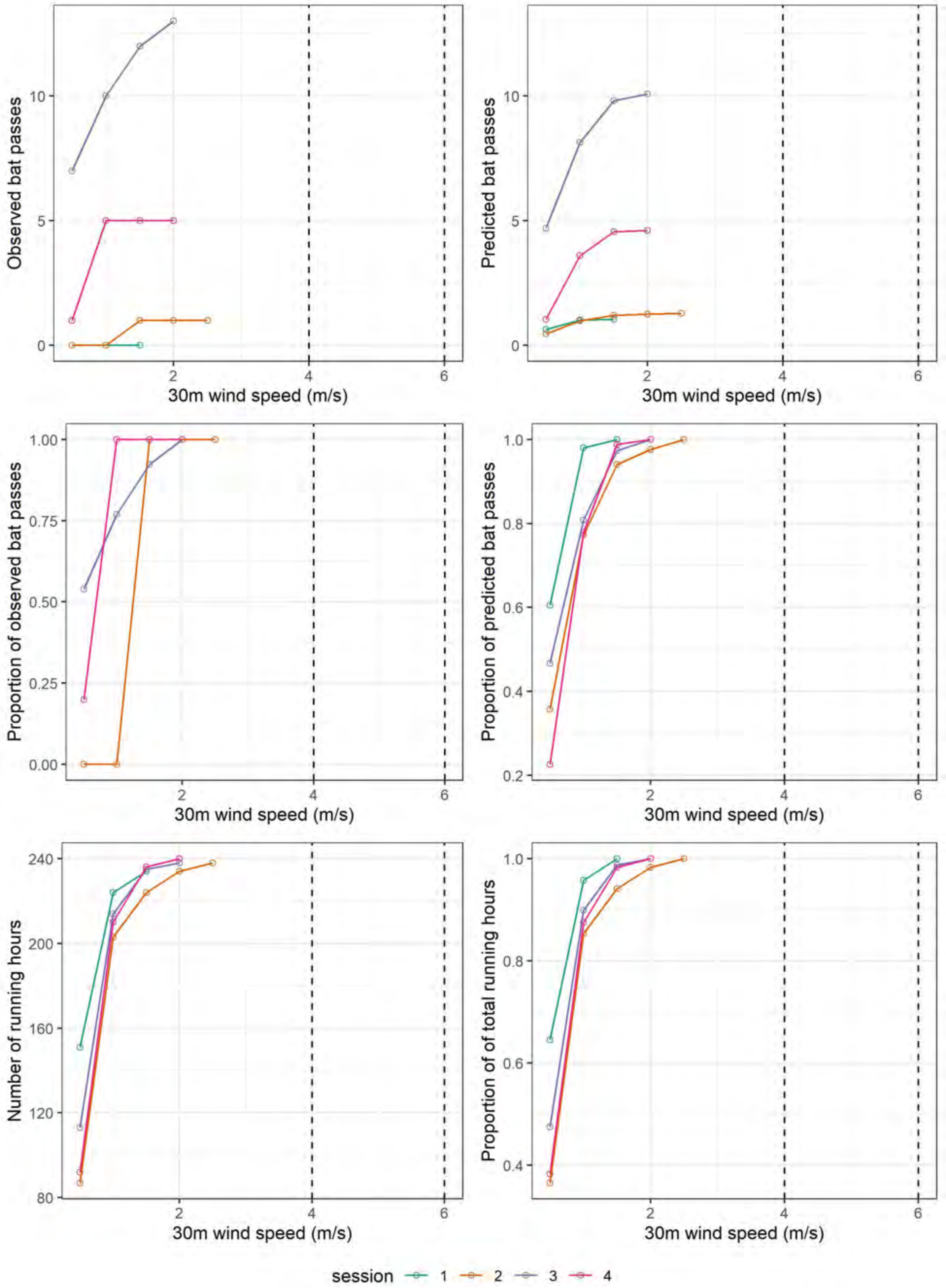

Figure B.12: Relationship between the presence or absence of observed and predicted hourly bat passes and wind speed (m/s) from the binomial model for ABM B64

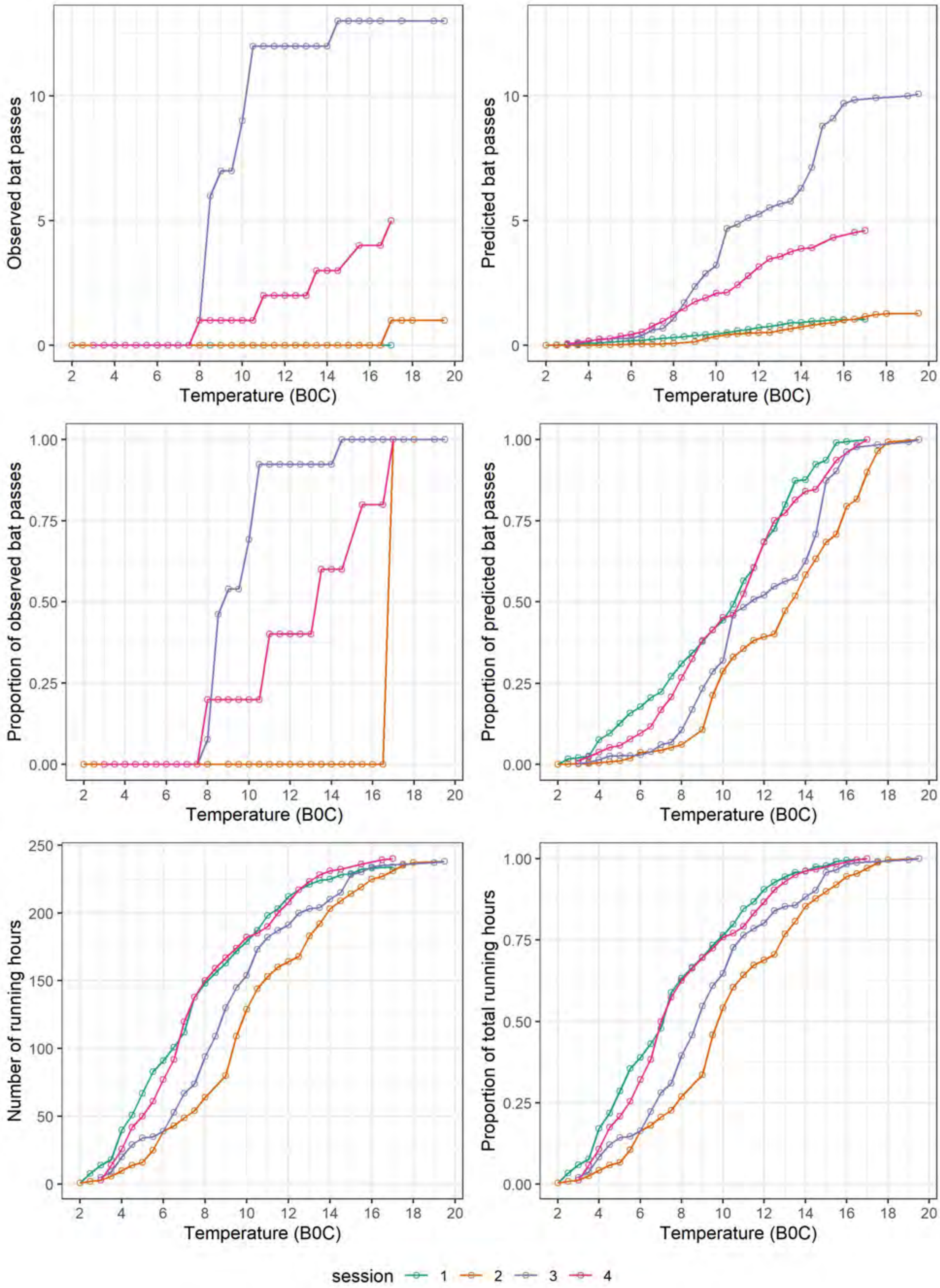

Figure B.13: Relationship between the presence or absence of observed and predicted hourly bat passes and temperature (°C) from the binomial model for ABM B64.

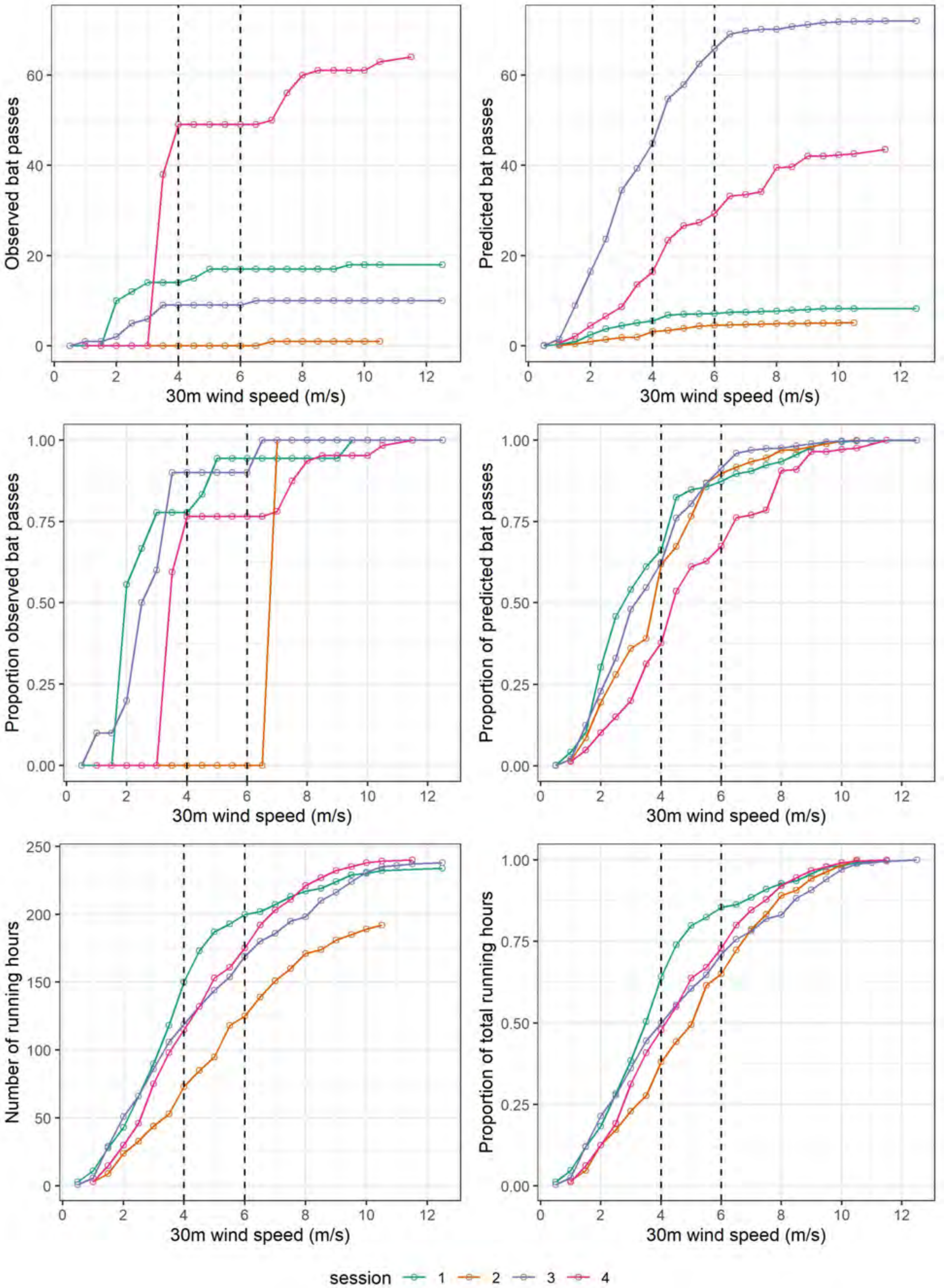

Figure B.14: Relationship between counts of observed and predicted hourly bat passes and wind speed (m/s) from the tweedie model for ABM B77

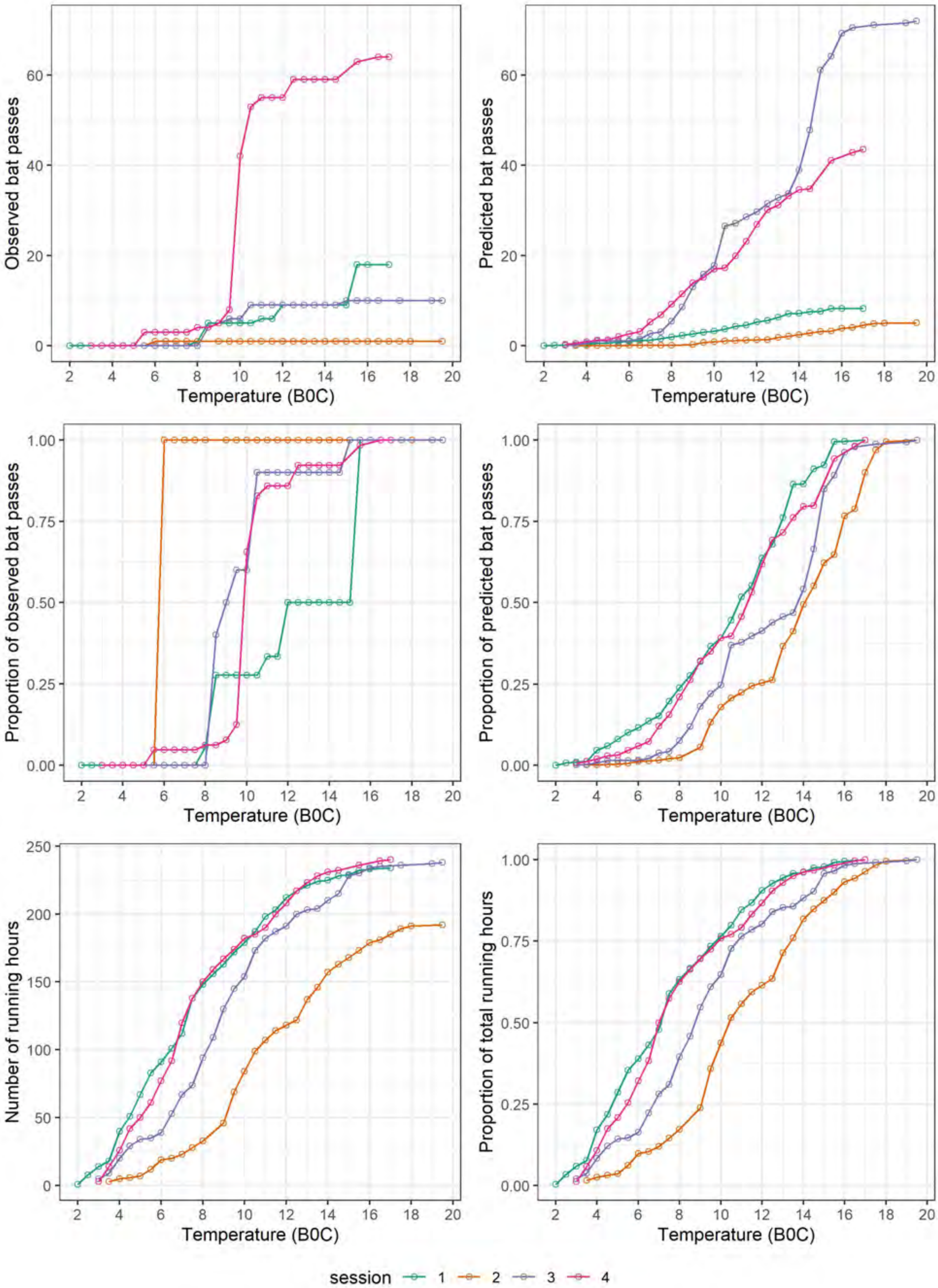

Figure B.15: Relationship between counts of observed and predicted hourly bat passes and temperature (°C) from the tweedie model for ABM B77.

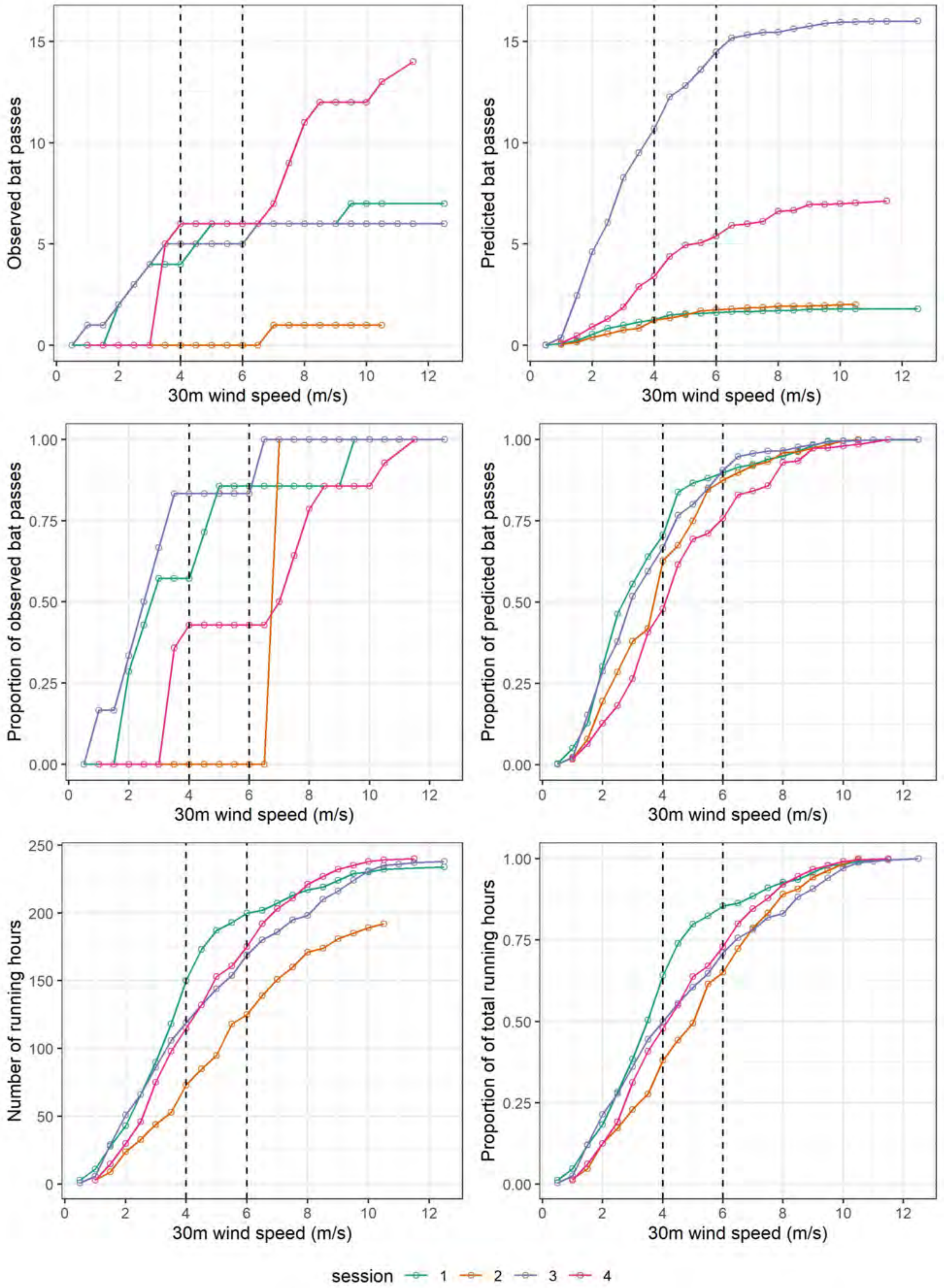

Figure B.16: Relationship between the presence or absence of observed and predicted hourly bat passes and wind speed (m/s) from the binomial model for ABM B77.

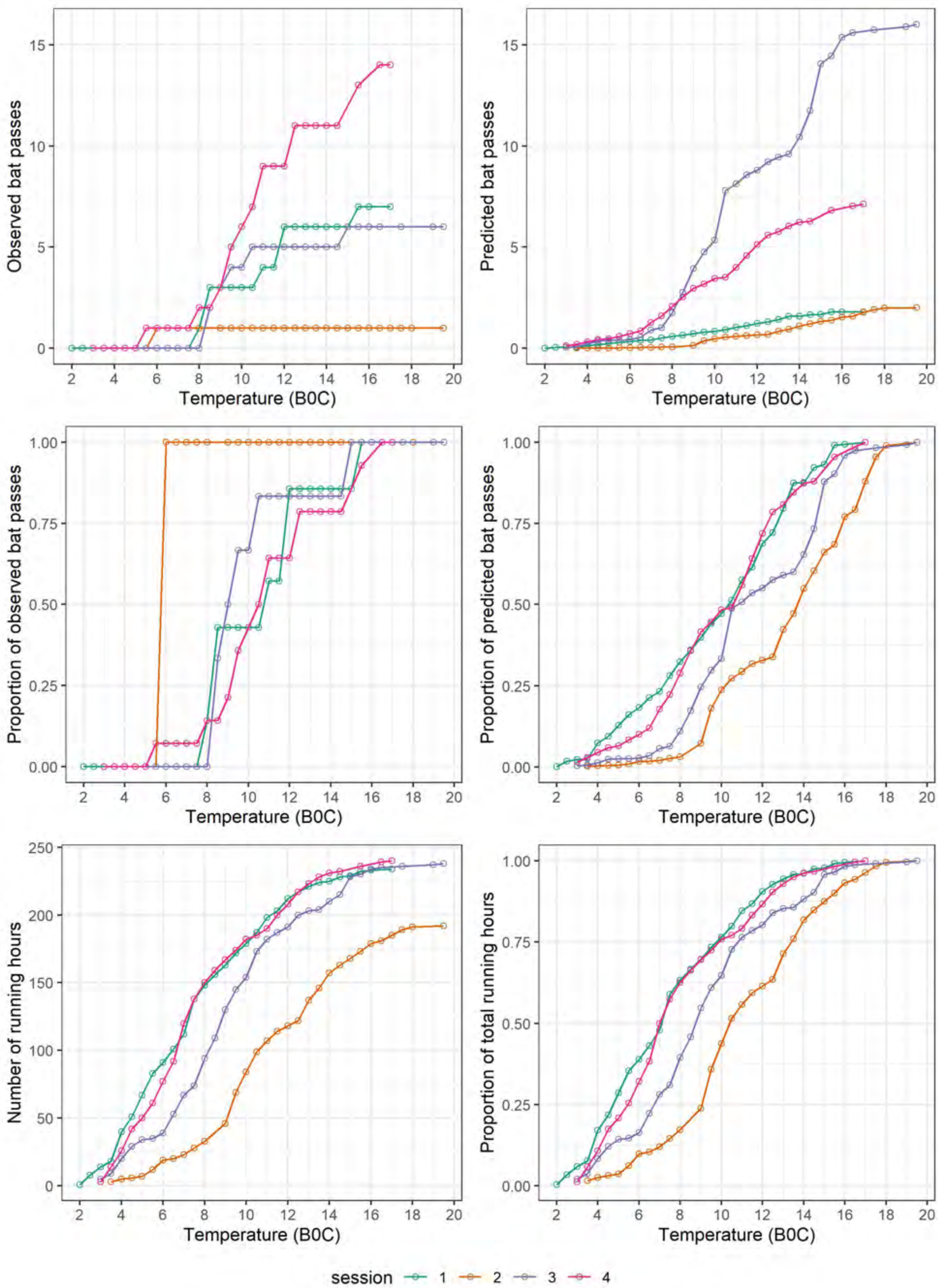

Figure B.17: Relationship between the presence or absence of observed and predicted hourly bat passes and temperature (°C) from the binomial model for ABM B77

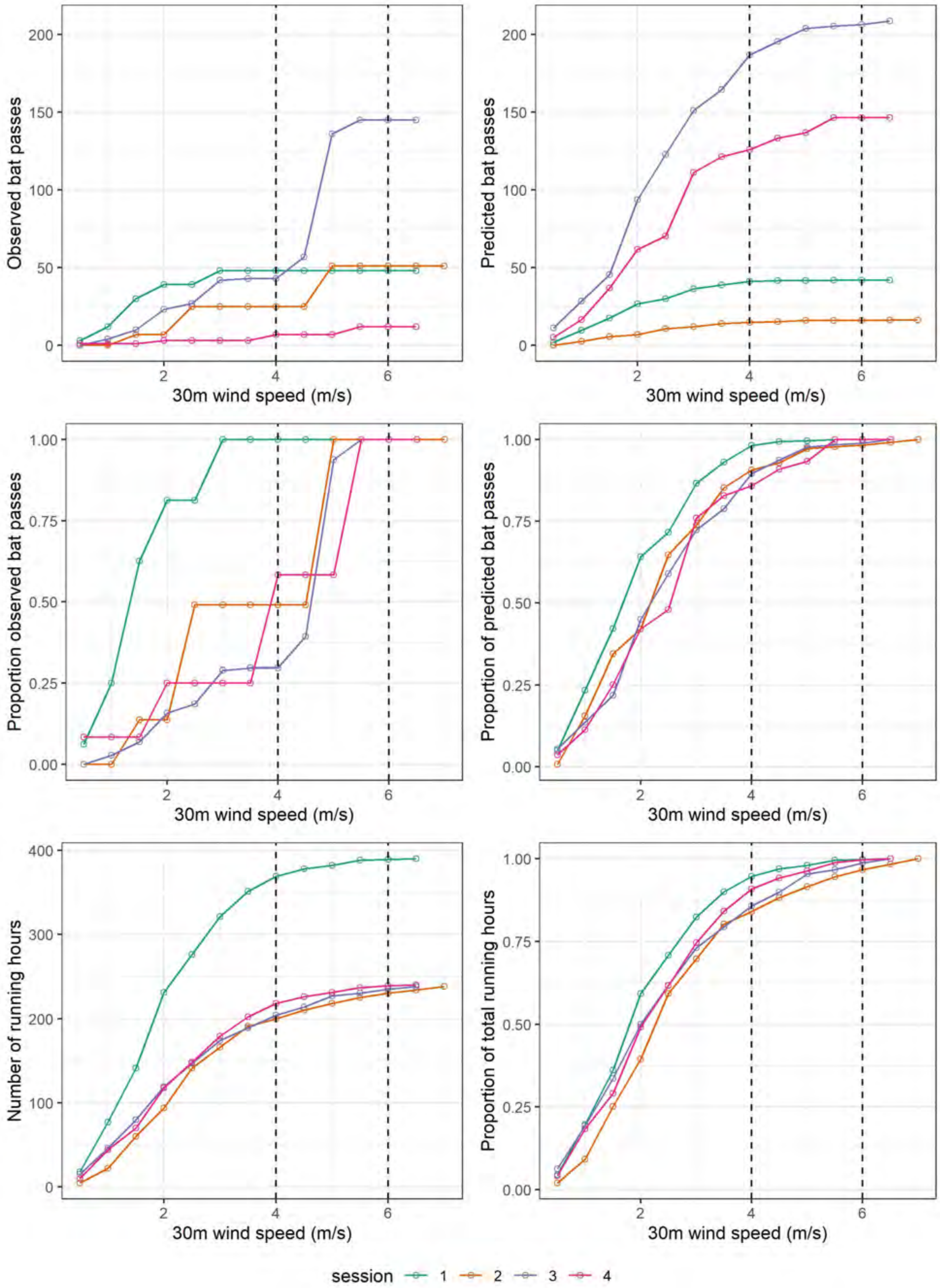

Figure B.18: Relationship between counts of observed and predicted hourly bat passes and wind speed (m/s) from the tweedie model for ABM B63.

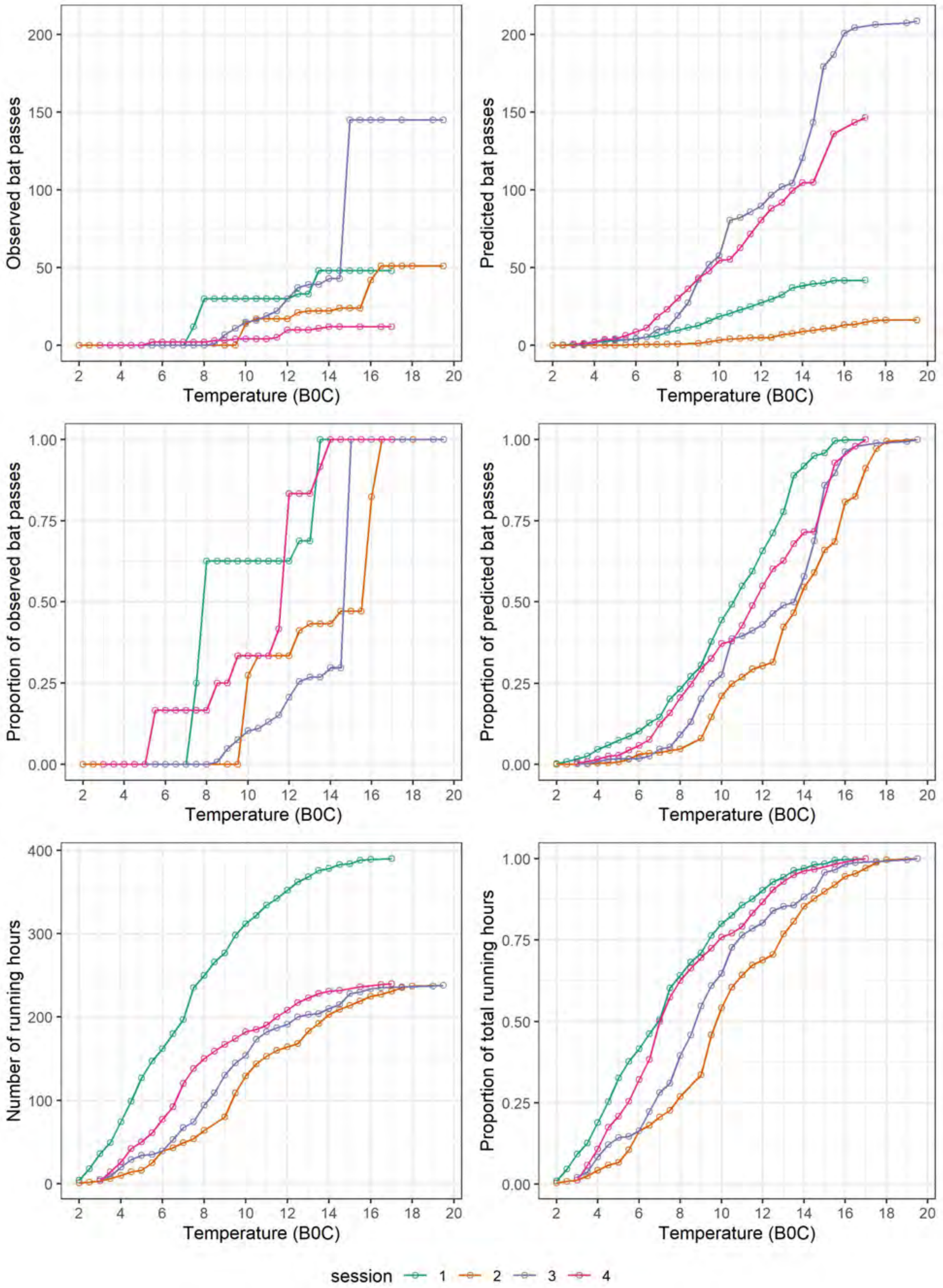

Figure B.19: Relationship between counts of observed and predicted hourly bat passes and temperature (°C) from the tweedie model for ABM B63.

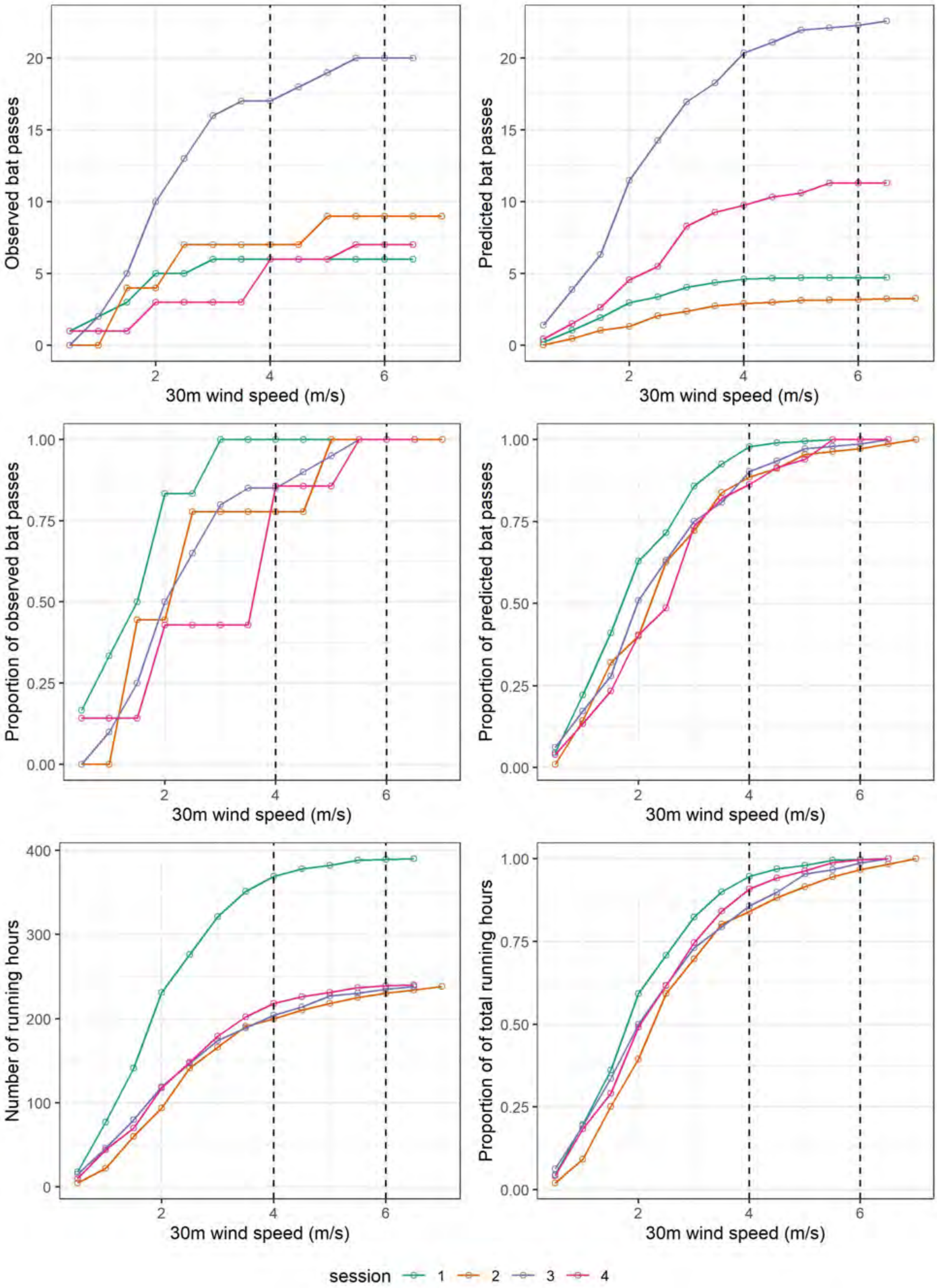

Figure B.20: Relationship between the presence or absence of observed and predicted hourly bat passes and wind speed (m/s) from the binomial model for ABM B63.

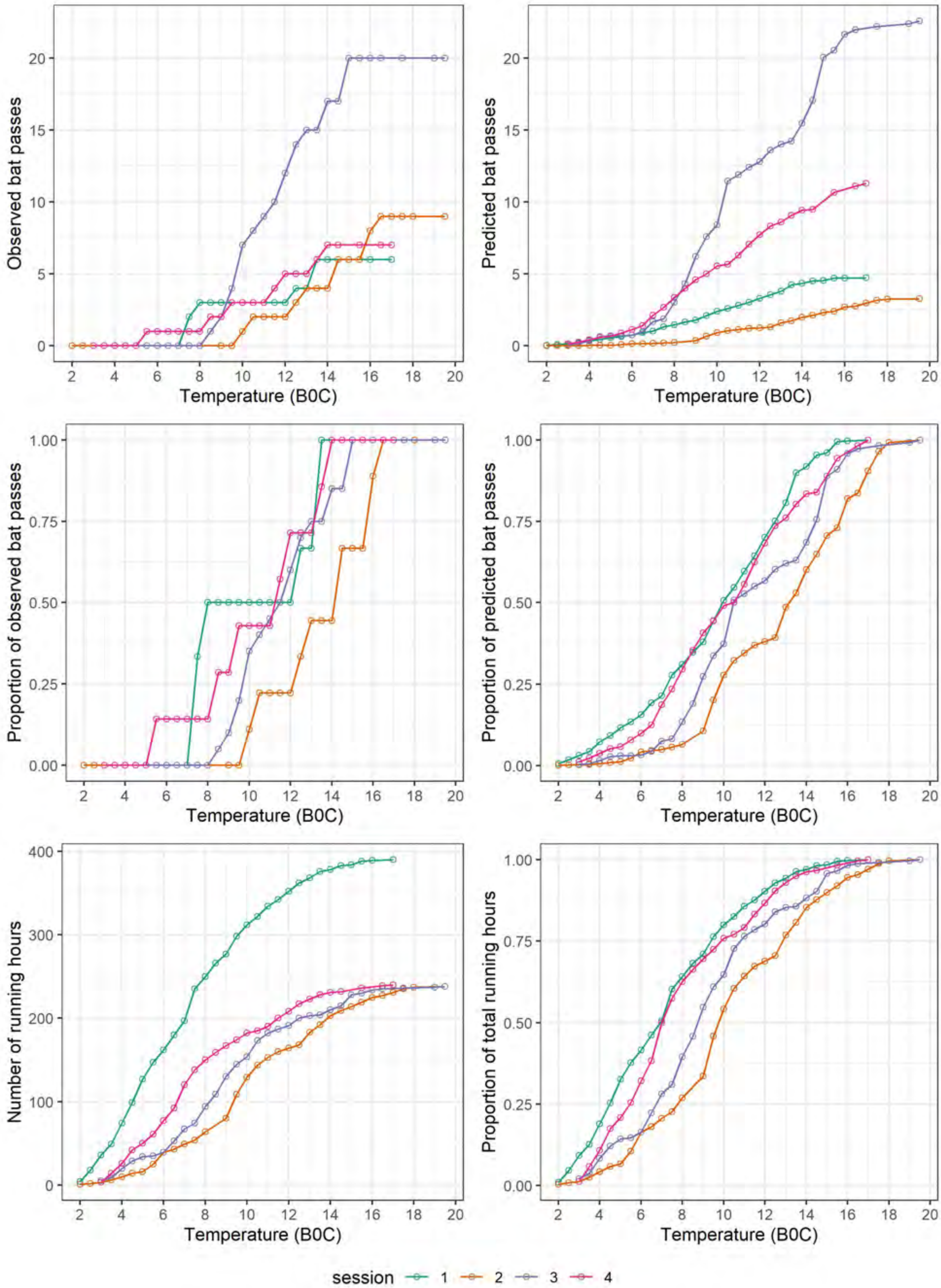

Figure B.21: Relationship between the presence or absence of observed and predicted hourly bat passes and temperature (°C) from the binomial model for ABM B63.

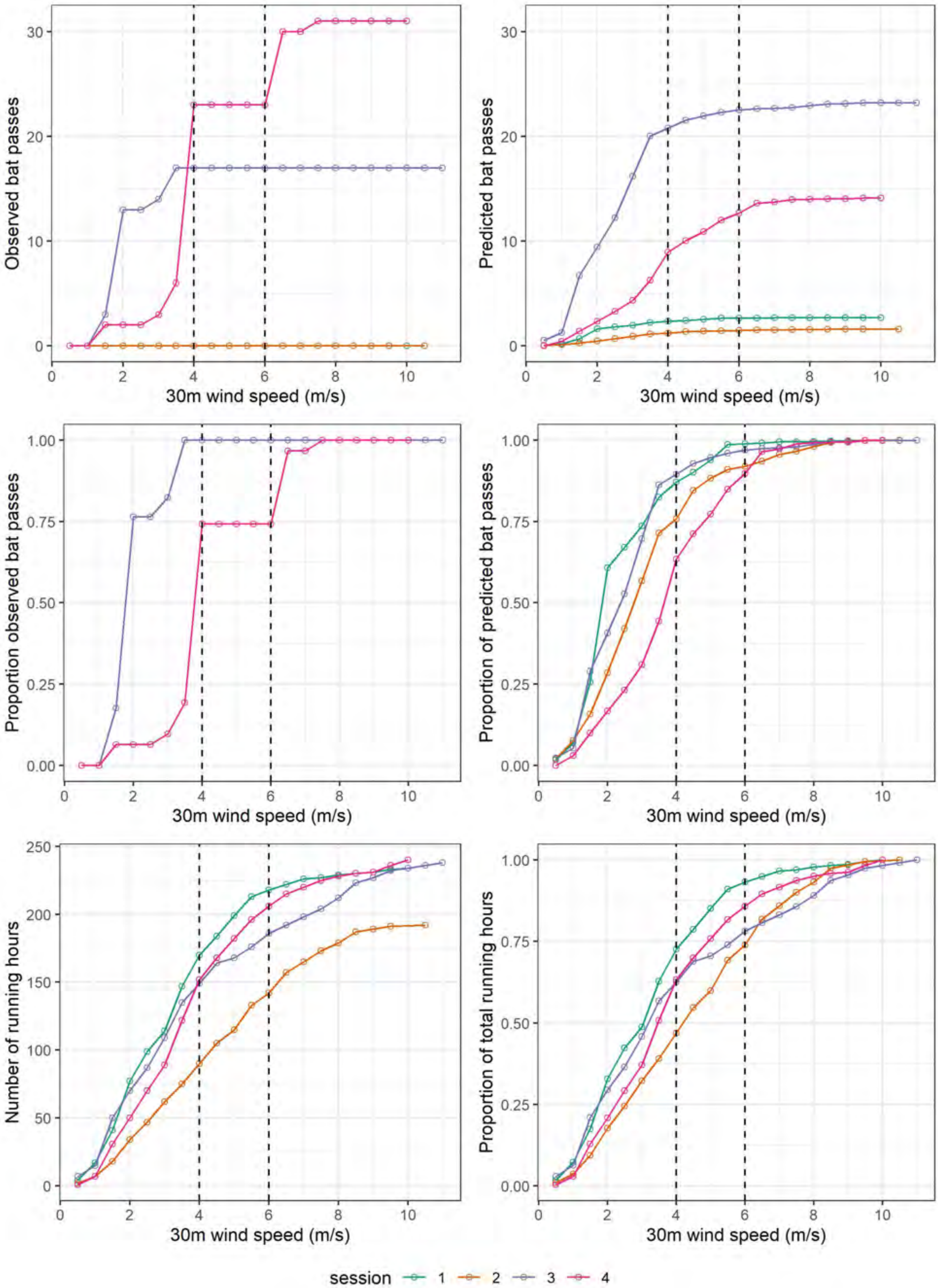

Figure B.22: Relationship between counts of observed and predicted hourly bat passes and wind speed (m/s) from the tweedie model for ABM B72.

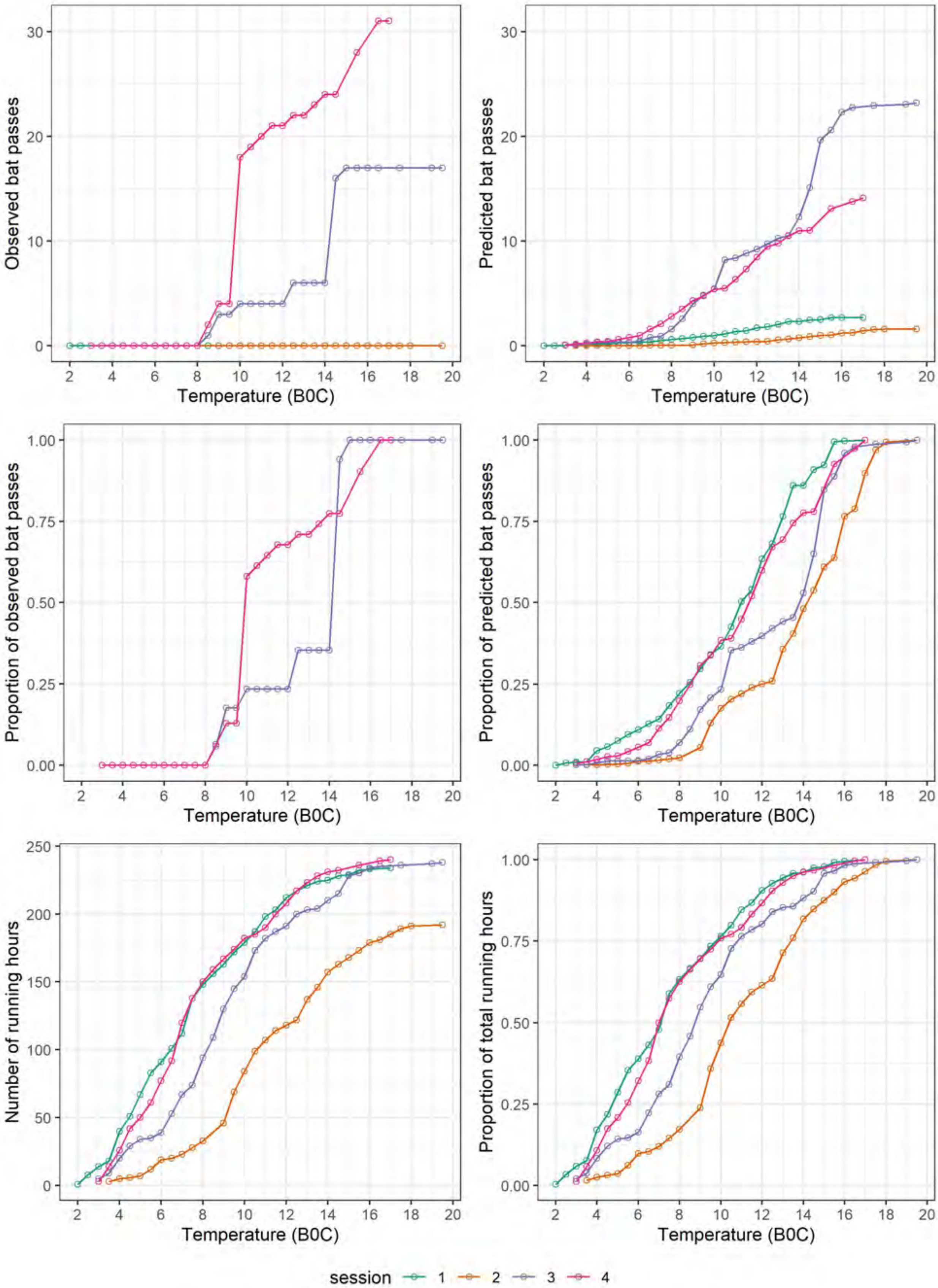

Figure B.23: Relationship between counts of observed and predicted hourly bat passes and temperature (°C) from the tweedie model for ABM B72.

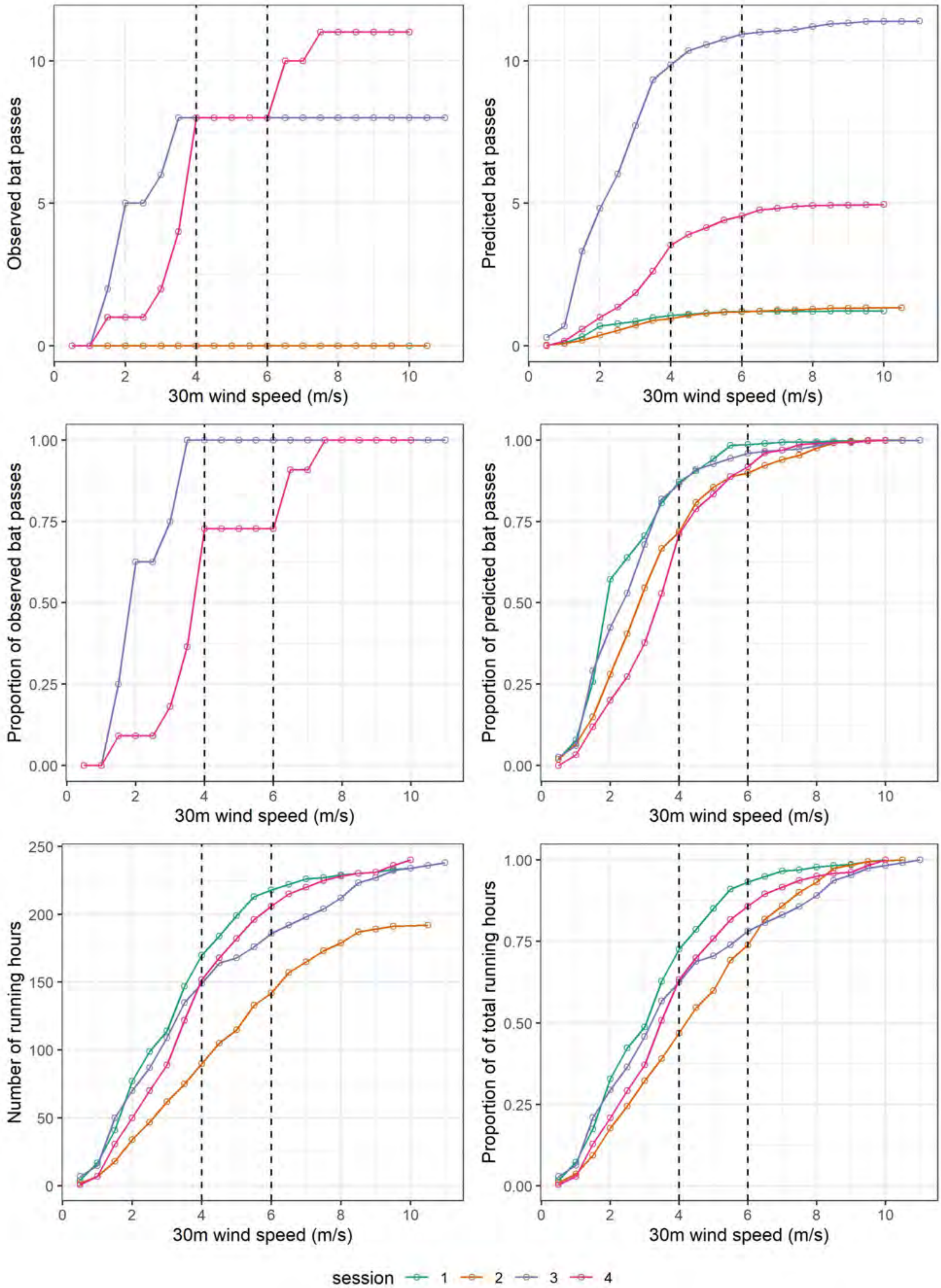

Figure B.24: Relationship between the presence or absence of observed and predicted hourly bat passes and wind speed (m/s) from the binomial model for ABM B72.

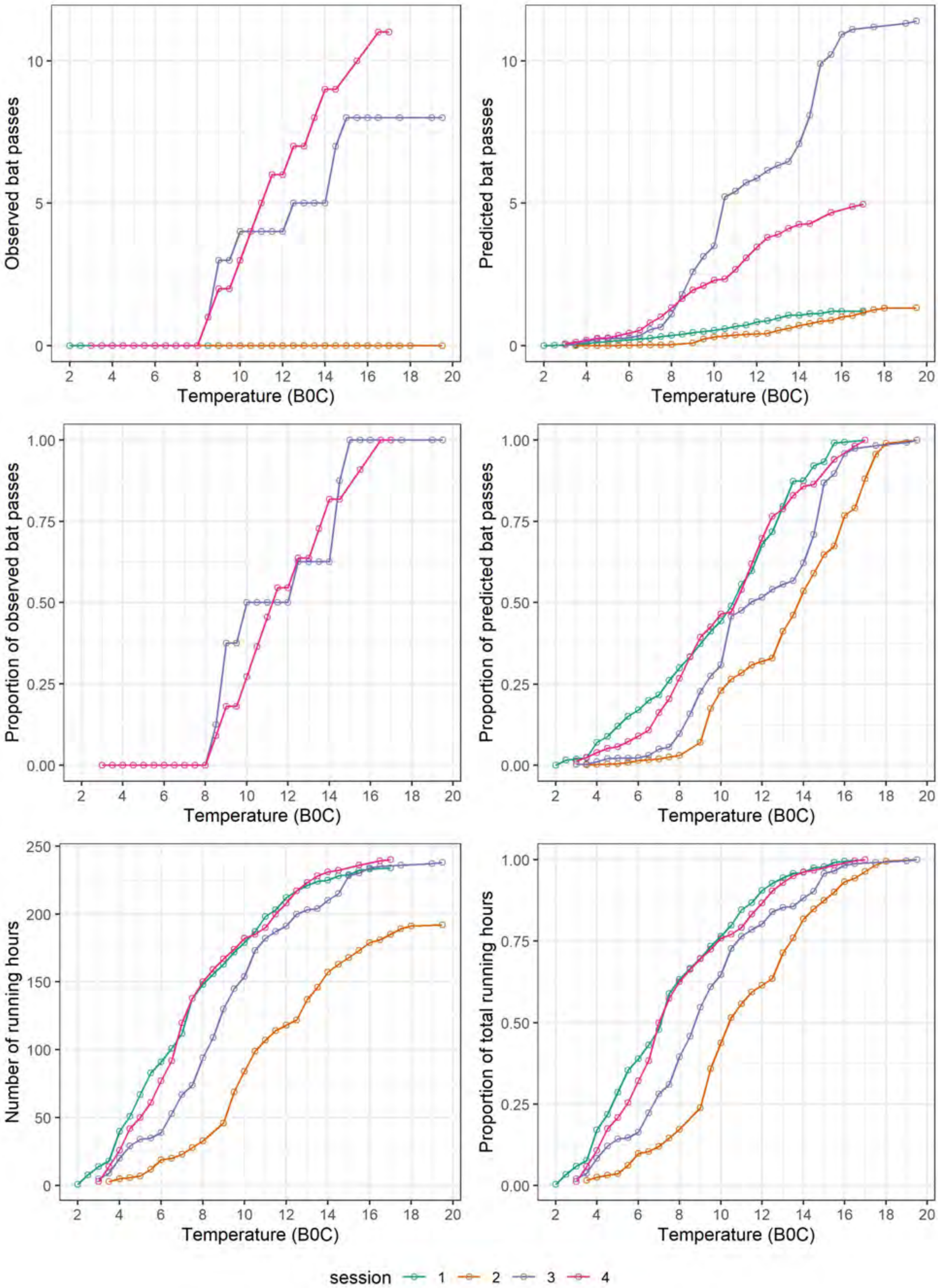

Figure B.25: Relationship between the presence or absence of observed and predicted hourly bat passes and temperature (°C) from the binomial model for ABM B72.

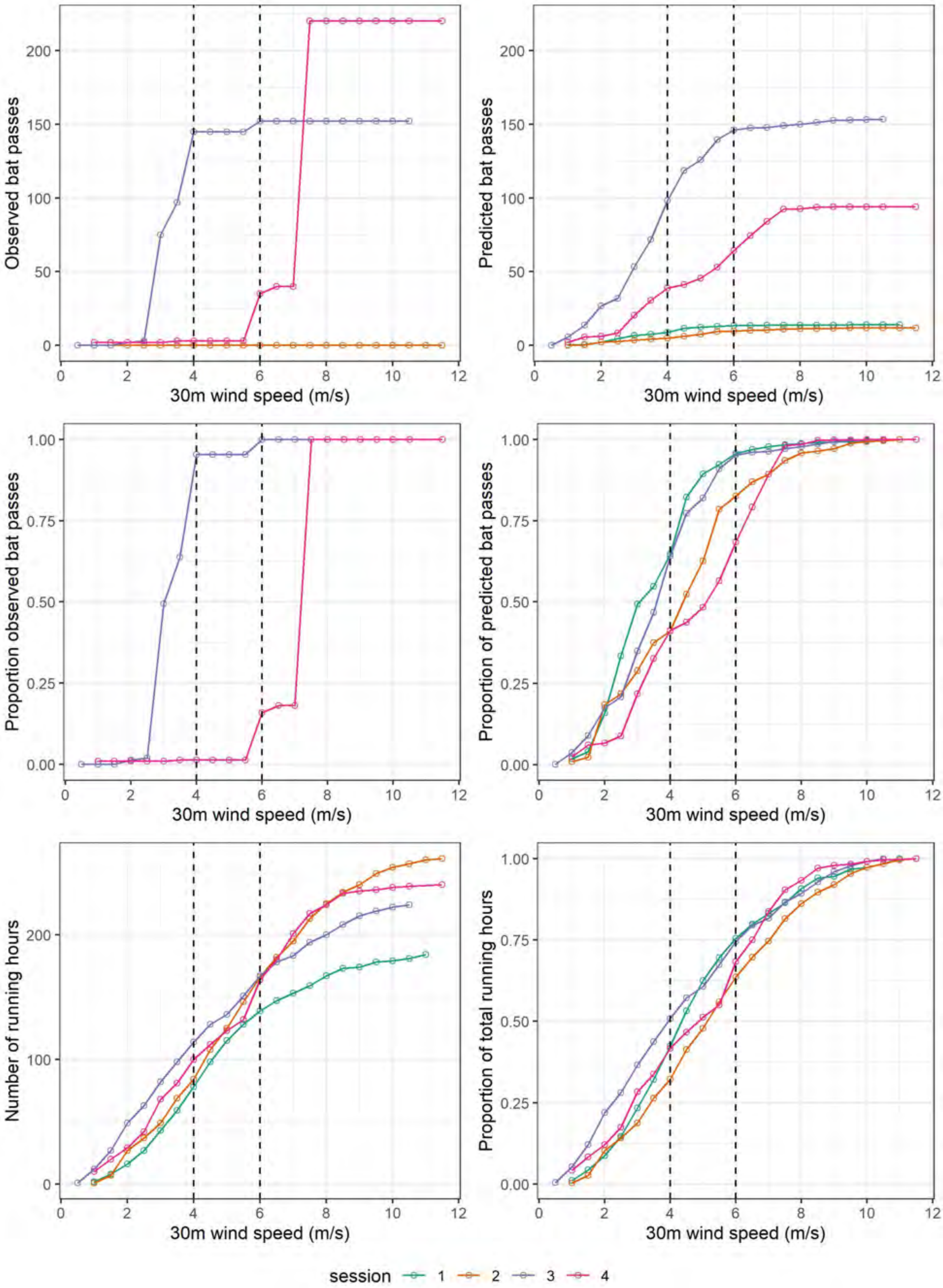

Figure B.26: Relationship between counts of observed and predicted hourly bat passes and wind speed (m/s) from the tweedie model for ABM B36.

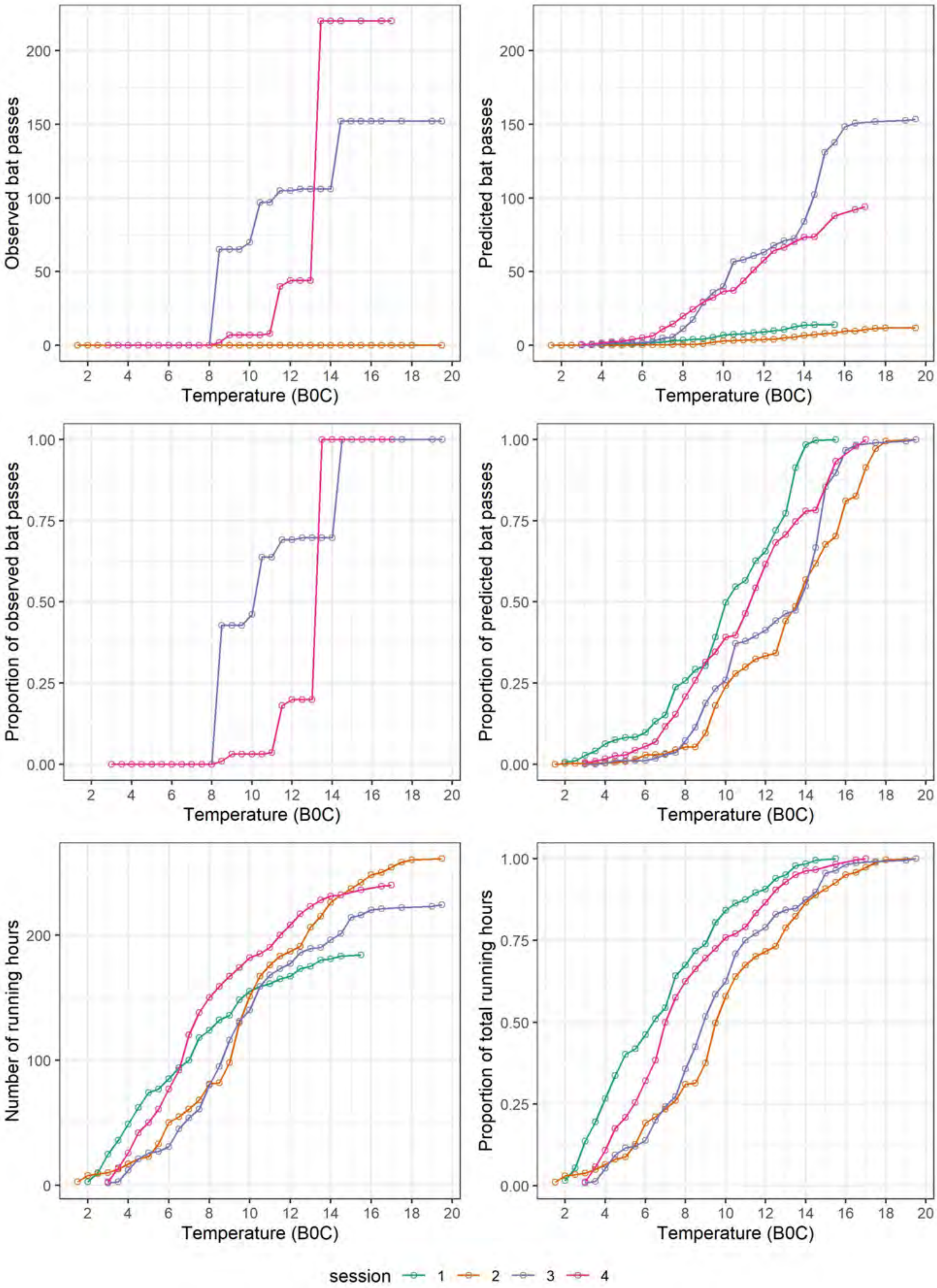

Figure B.27: Relationship between counts of observed and predicted hourly bat passes and temperature (°C) from the tweedie model for ABM B36.

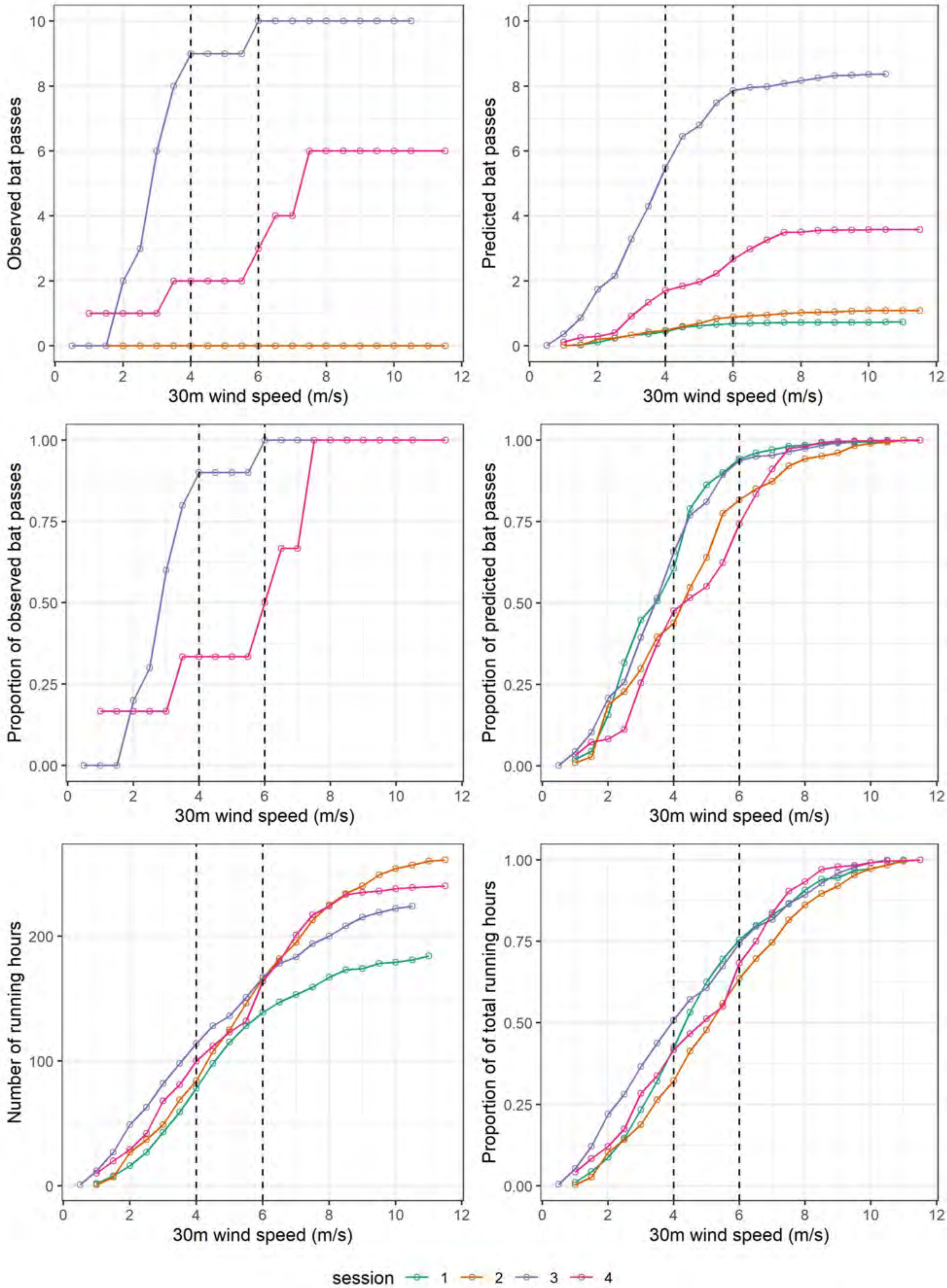

Figure B.28: Relationship between the presence or absence of observed and predicted hourly bat passes and wind speed (m/s) from the binomial model for ABM B36.

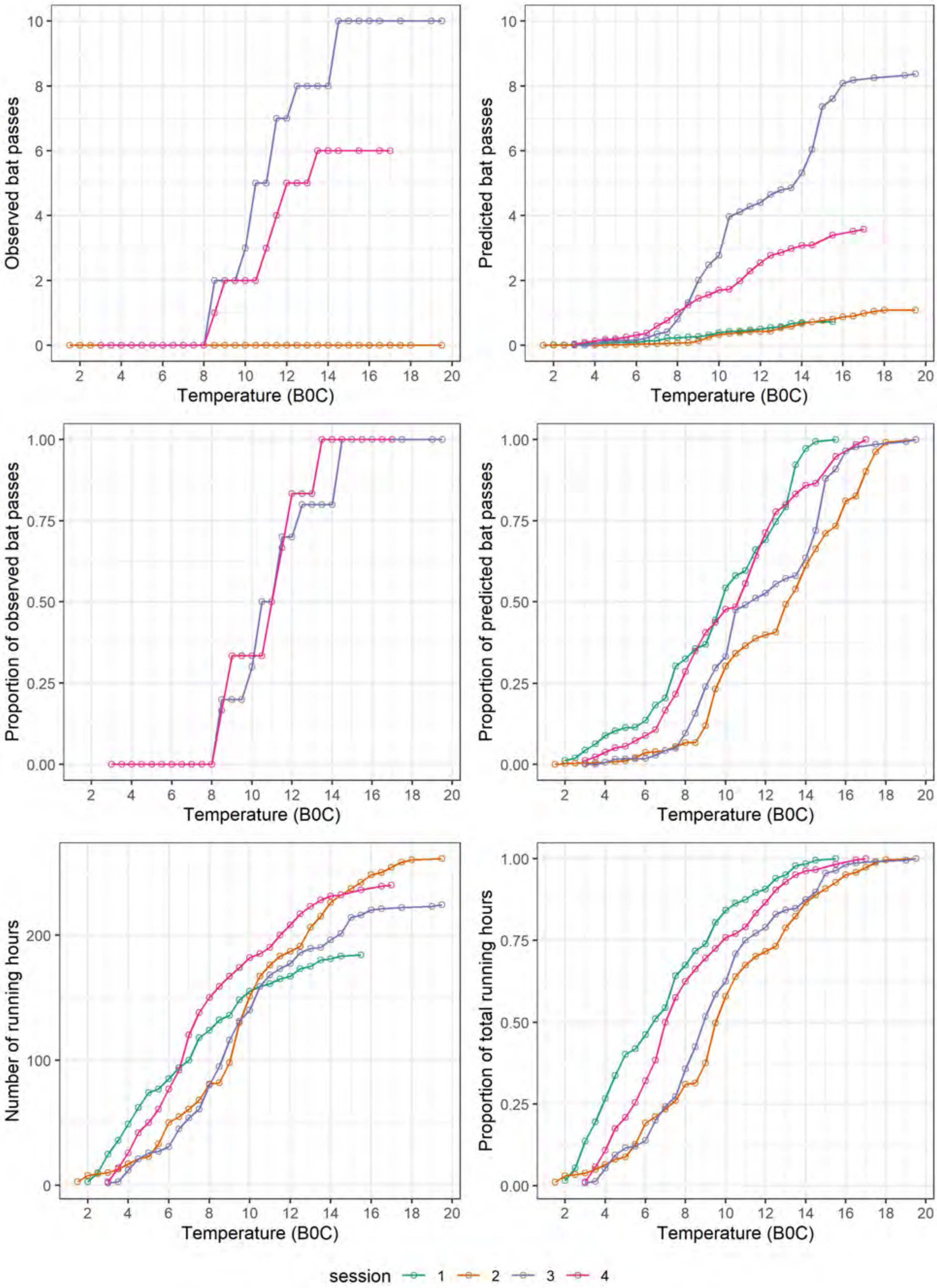

Figure B.29: Relationship between the presence or absence of observed and predicted hourly bat passes and temperature (°C) from the binomial model for ABM B36.

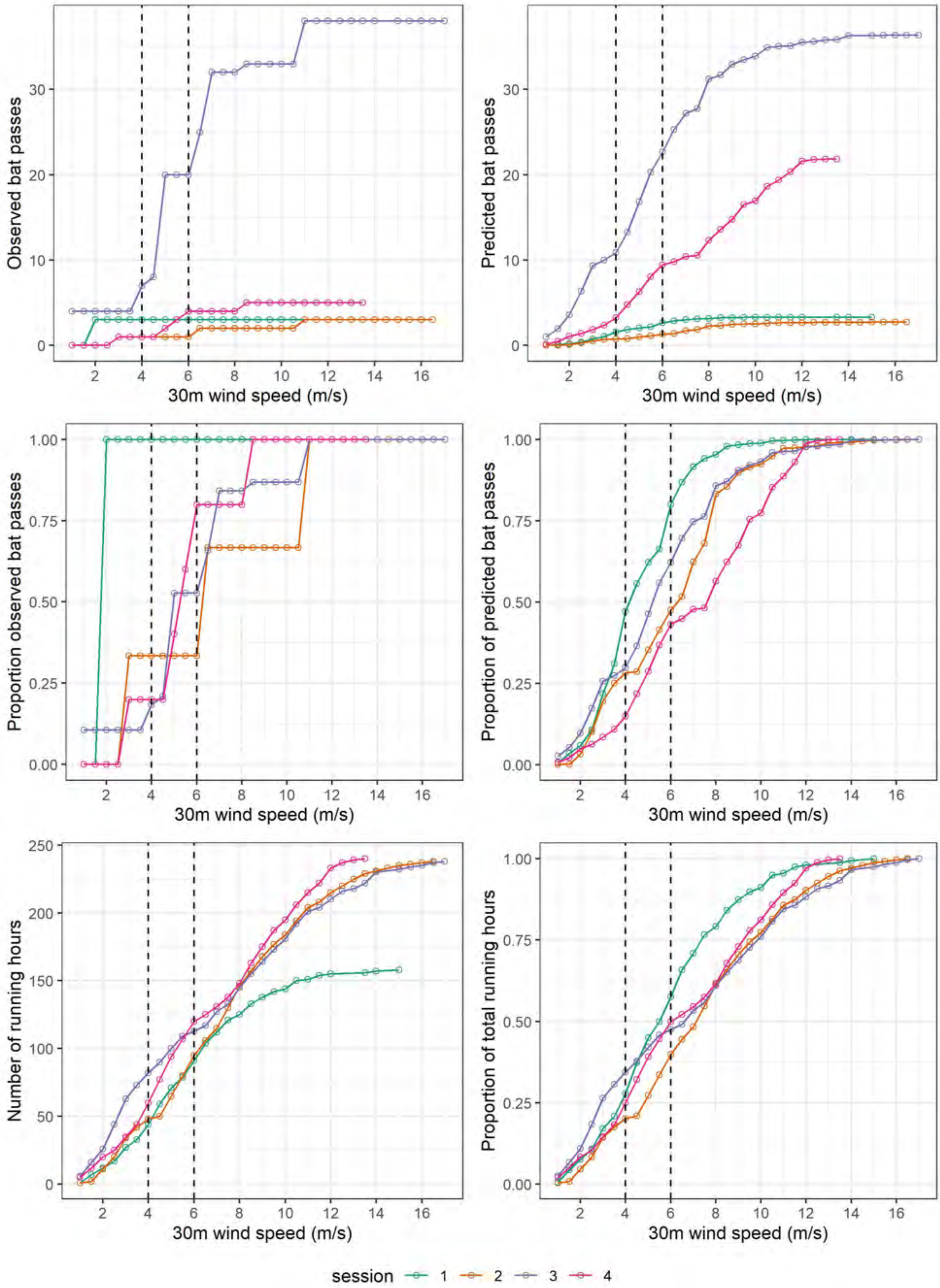

Figure B.30: Relationship between counts of observed and predicted hourly bat passes and wind speed (m/s) from the tweedie model for ABM B54.

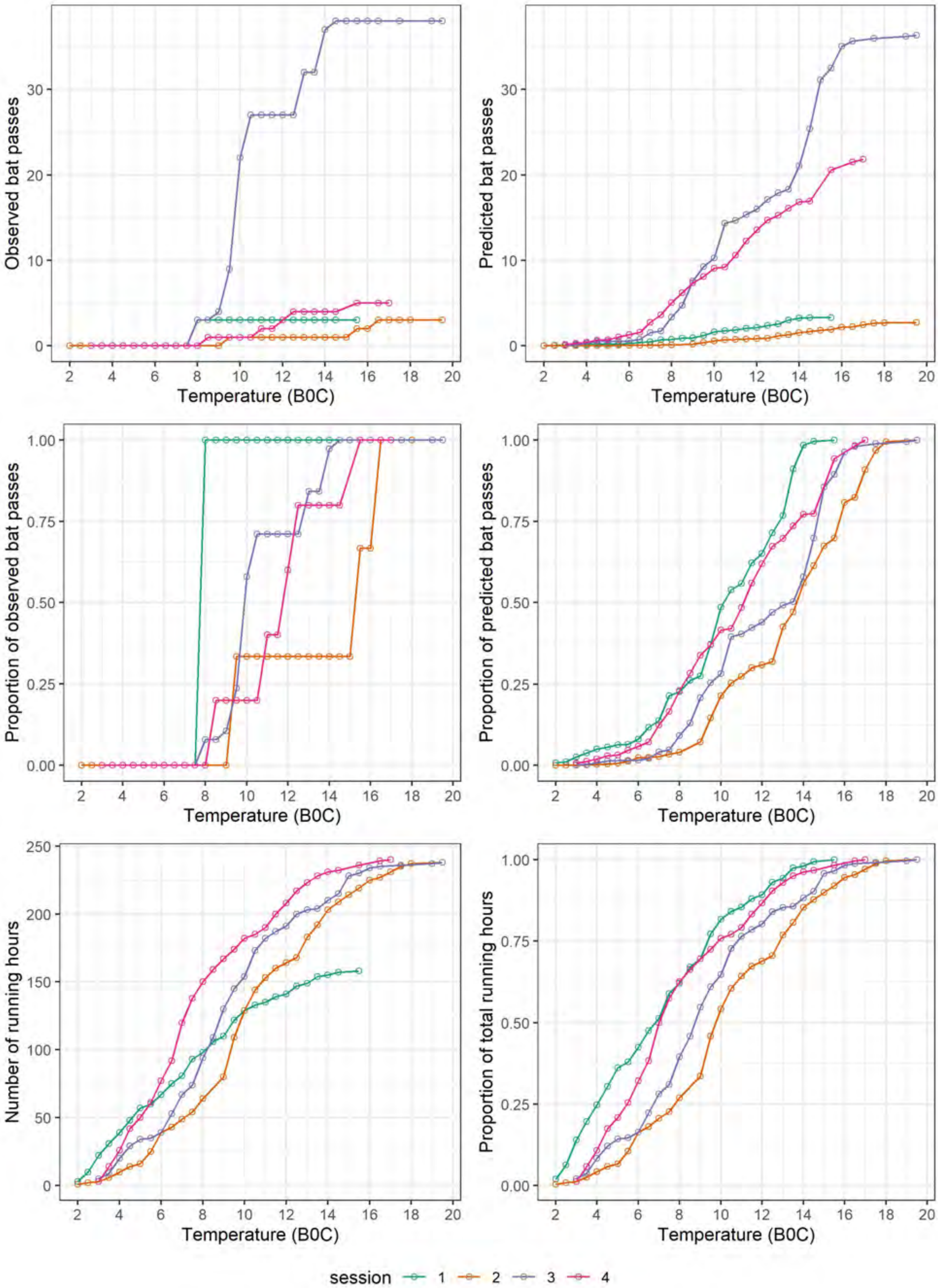

Figure B.31: Relationship between counts of observed and predicted hourly bat passes and temperature (°C) from the tweedie model for ABM B54.

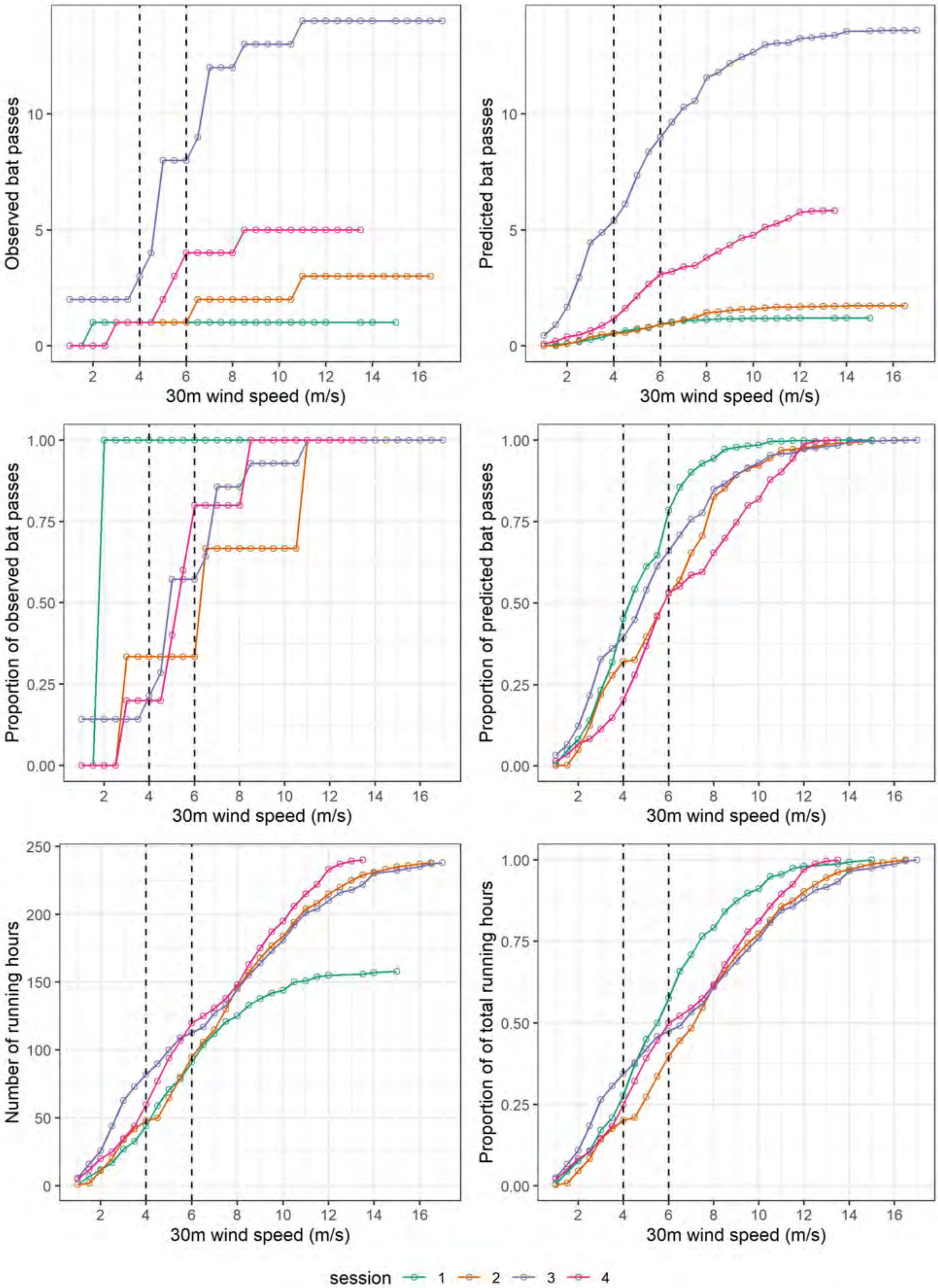

Figure B.32: Relationship between the presence or absence of observed and predicted hourly bat passes and wind speed (m/s) from the binomial model for ABM B54.

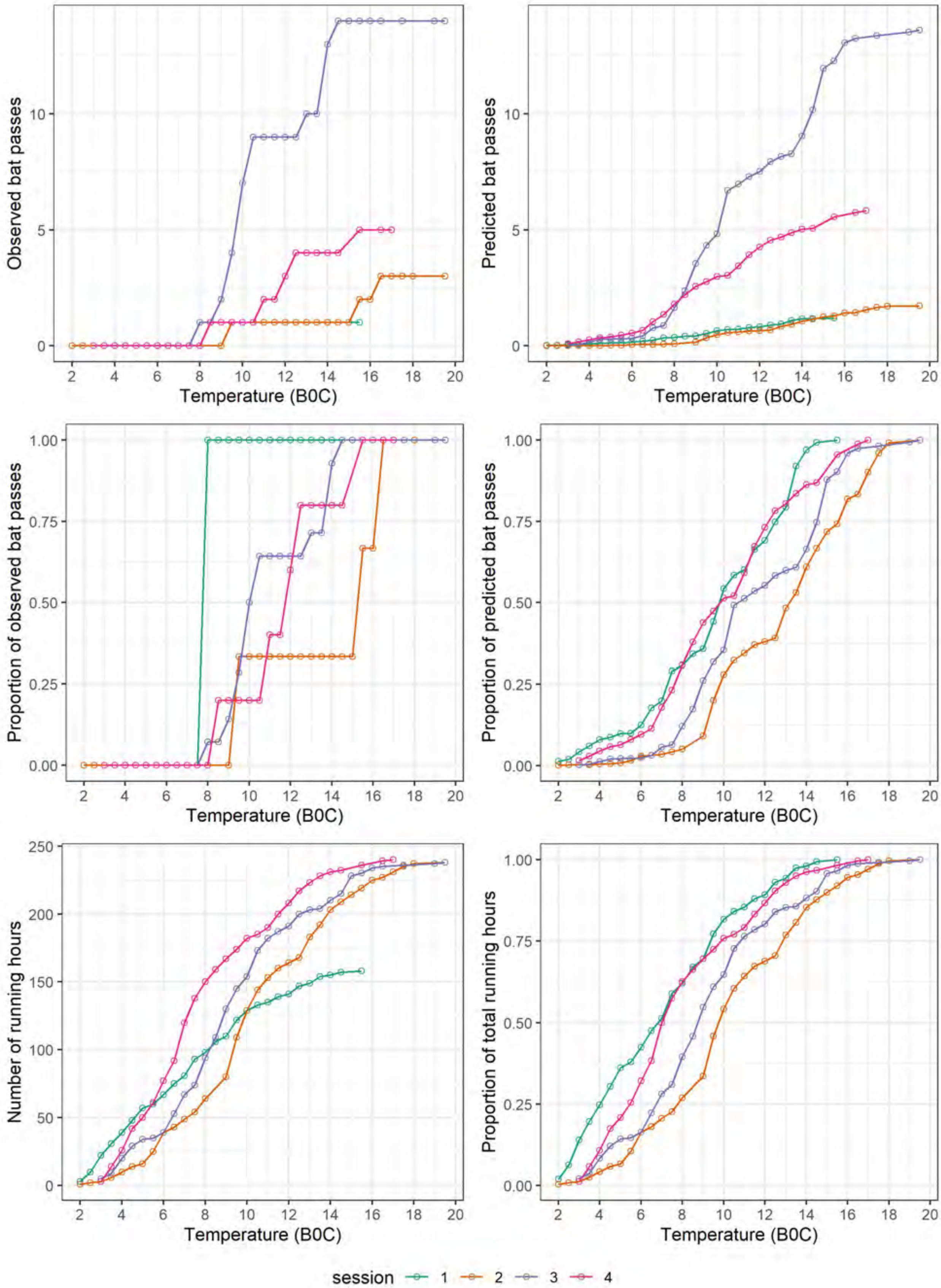

Figure B.33: Relationship between the presence or absence of observed and predicted hourly bat passes and temperature (°C) from the binomial model for ABM B54.

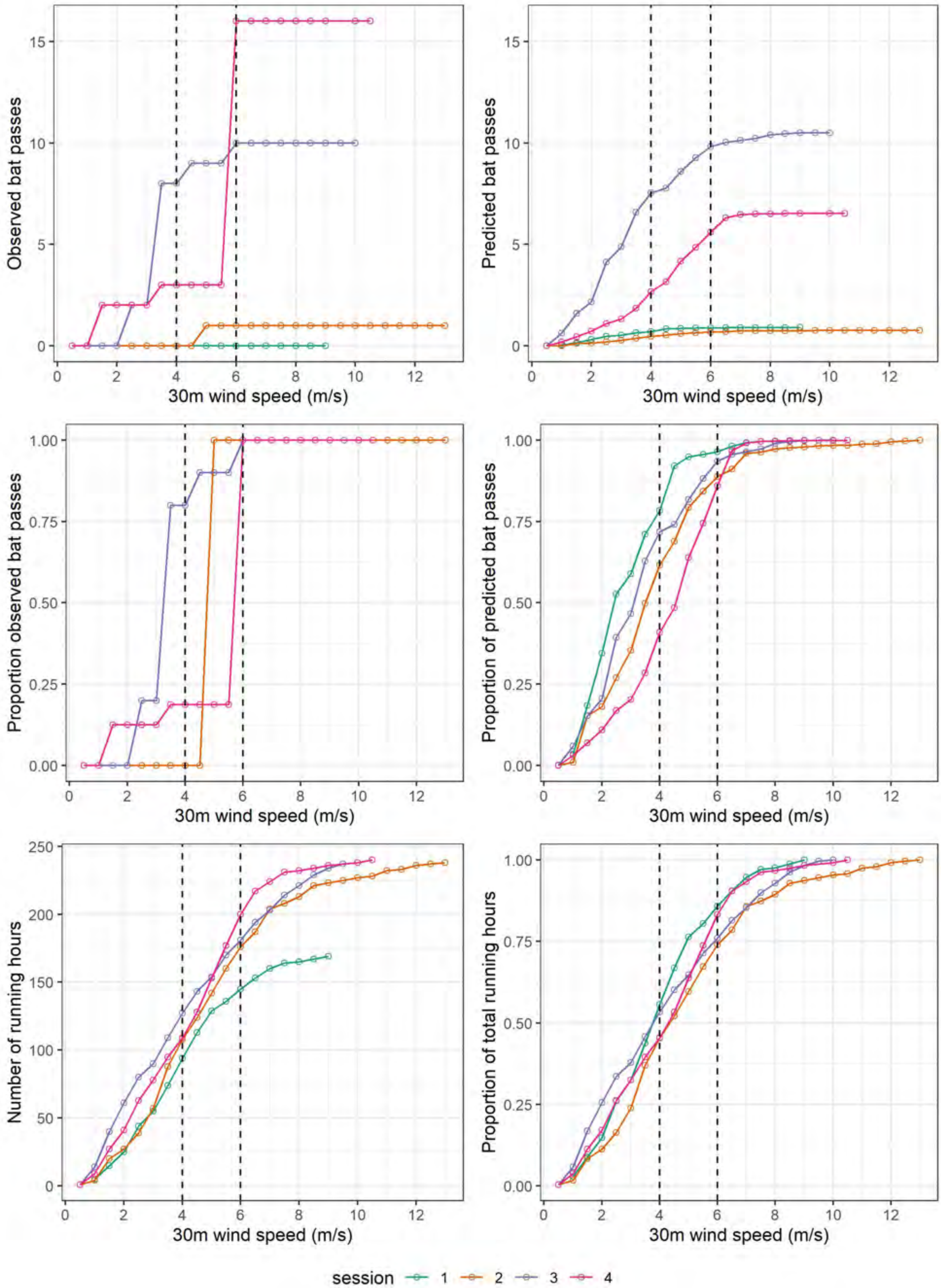

Figure B.34: Relationship between counts of observed and predicted hourly bat passes and wind speed (m/s) from the tweedie model for ABM B61.

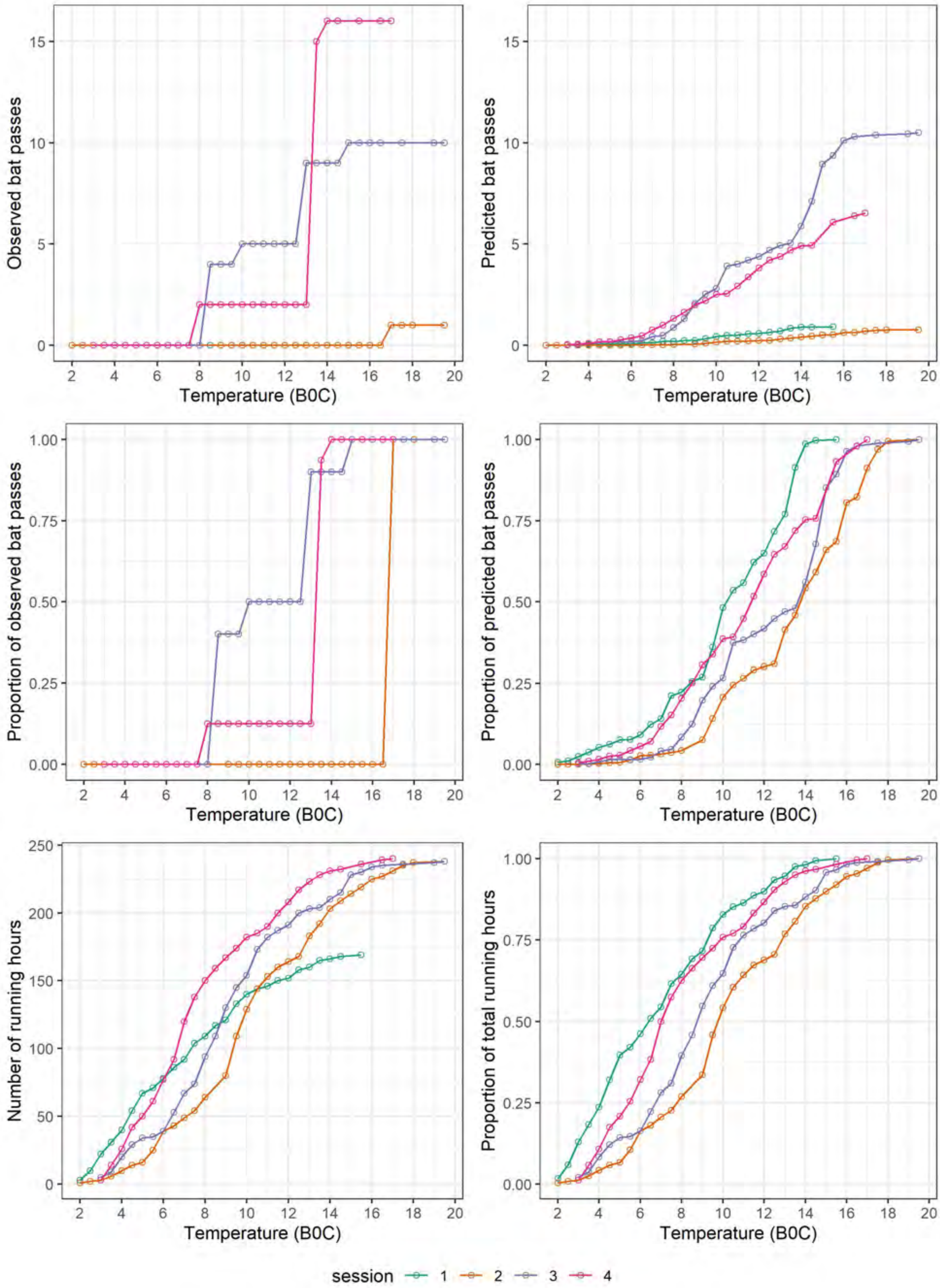

Figure B.35: Relationship between counts of observed and predicted hourly bat passes and temperature (°C) from the tweedie model for ABM B61.

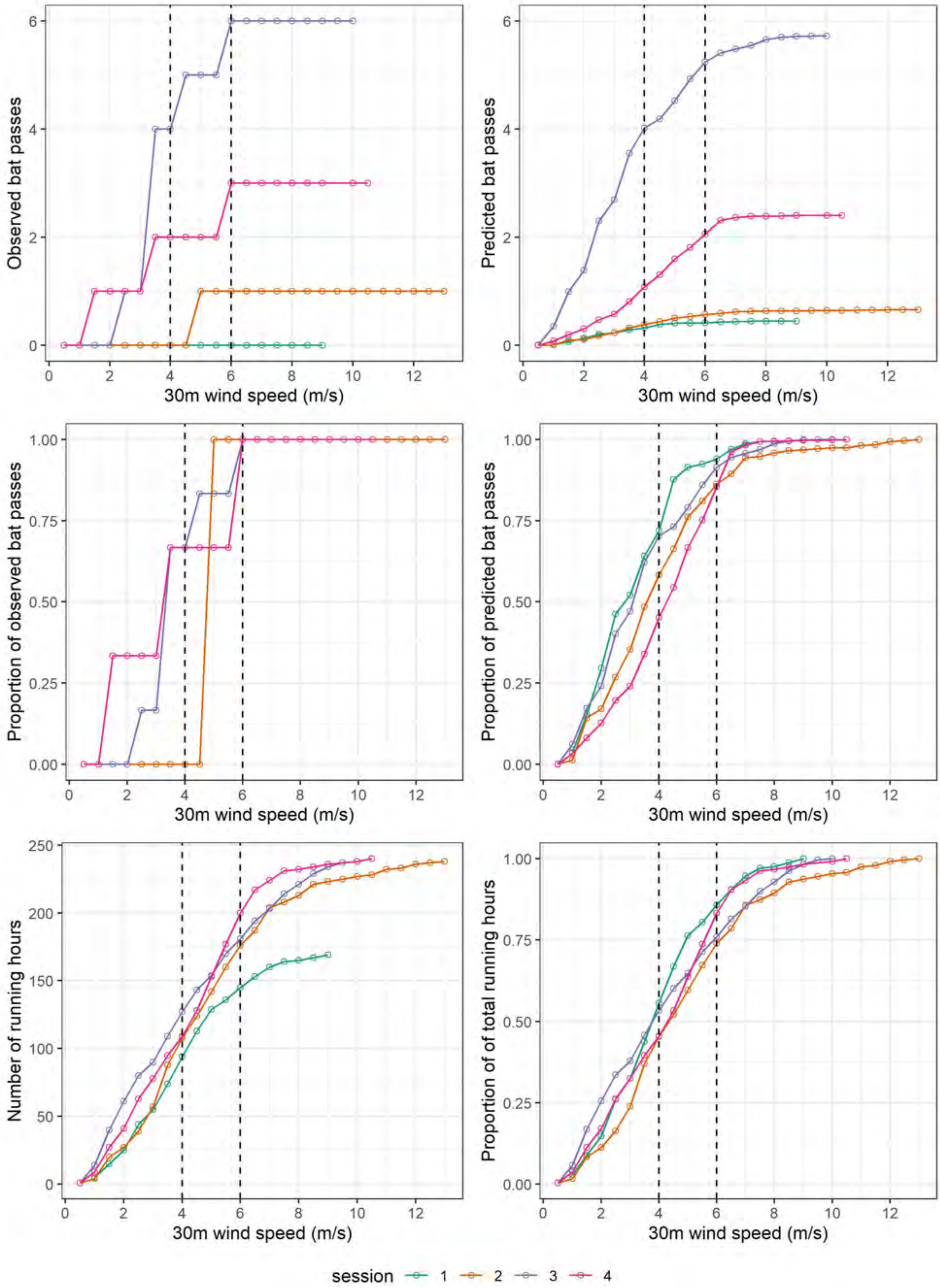

Figure B.36: Relationship between the presence or absence of observed and predicted hourly bat passes and wind speed (m/s) from the binomial model for ABM B61.

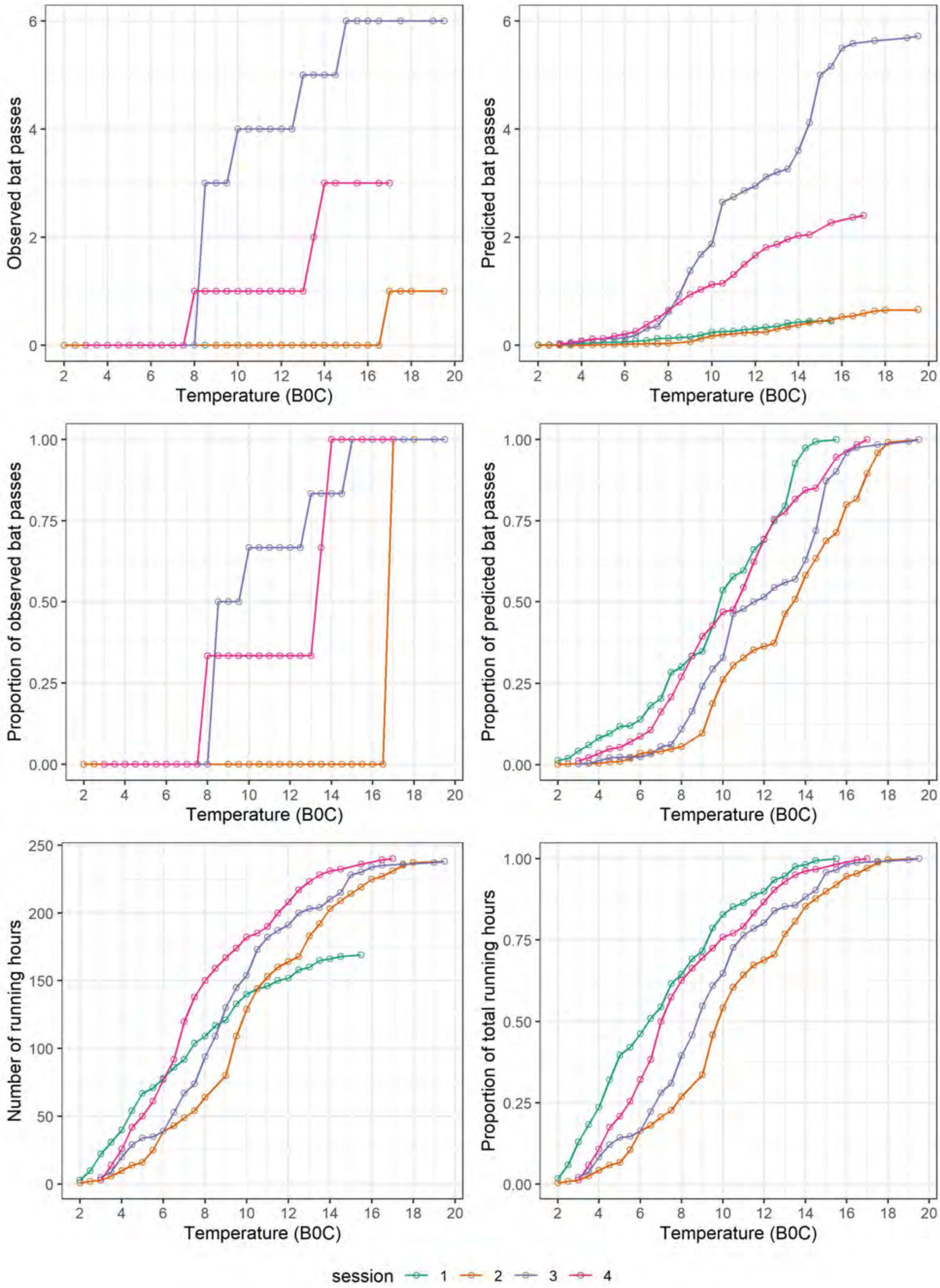

Figure B.37: Relationship between the presence or absence of observed and predicted hourly bat passes and temperature (°C) from the binomial model for ABM B61.

C Generalised linear model overview

The primary method of analysis in this report is a generalised linear (mixed) model, which uses a linear equation to describe the mean, or expected, value for a response variable of interest as a function of predictor variables. The expected value will therefore be different for different combinations of predictor variable values. How the variation in the data around the expected value is described, the nature of that variation, and the specifics of the analysis, depends on what distribution is assumed for the data. In this case, the Tweedie distribution has been assumed for the bat call count data, and binomial distribution for the bat call presence-absence data. For example, if μ_{ij} is the expected number of bat calls in an hour (denoted by i) at ABM j, and that is to be described as a function of the predictor variables; 1) wind speed in that hour (W_i); 2) distance from river to the ABM (D_j) and vegetation height (V_j), the linear equation would be:

$$log(\mu_i) = \beta_0 + \beta_1 W_i + \beta_2 D_j + \beta_3 V_j,$$

where β_0 is the intercept term (which determines μ_{ij} where the value of all predictor variables, or covariates, in the equation is zero), and β_1-β_3 are the regression coefficients, or effect sizes, for the predictor variables. These determine how much the value of μ_{ij} will change for a one-unit change in the value of the respective predictor variable, where the size of a one-unit change depends on the scale of predictor used in the analysis (e.g., if distance measured in metre or 100 metre units). A value of zero for a coefficient would imply that predictor variable has no effect on the expected value of the count. Note that the modelling is done on the scale of $log(\mu_{ij})$ as μ_{ij} must be > 0 when interest is in count data (i.e., can only take integer values ≥ 0), therefore interpretation of the regression coefficients (of the bat call count data) is also on the log-scale.

The purpose of the analyses are to estimate the size the coefficients from the data, to indicate the magnitude of the effect on the expected value. The statistical evidence for the strength of an effect depends on how precisely that effect is estimated from the data. Note that it is possible to have small effects that appear to be statistically important, and large effects that are statistically unimportant, but the ultimate consideration of the results is whether the effects appear to be practically important, which requires some input from subject-matter experts.

Results of the analyses are typically summarised in a table of estimated coefficient values, and often the tables would include values for:

- estimated coefficients; the change in the expected value for a one-unit change in the predictor variable, holding other variables constant.

- standard errors (SE); a measure of the precision of these estimates, where smaller SEs indicate more precise estimates.
- 95% confidence interval provides a range within which we are 95% confident the true value of the estimated coefficient lies. A narrower interval indicates more precision, while a wider interval suggests more uncertainty about the true value.
- t-value; a statistic that tests whether a coefficient is significantly different from zero, with larger absolute values indicating stronger evidence against the null hypothesis of no effect.
- p-value; the probability that the observed relationship happened by chance. A small p-value indicates stronger evidence for the rejection of the null hypothesis of no effect. It is derived from the t-value statistic.

D Reinterperation of continuous covariate effects

Interpretation of regression coefficients, the estimate effect size of covariates included in the models, can be difficult when the coefficients are on different scales. In an effort to provide further context, Tables D.1 and D.2 present the change in the value of a covariate that would result in a halving of the predicted bat activity per hour (either in terms of number of bat calls, or bat call presence, respectively). Values were calculated as:

$$V_{0.5,x} = \frac{ln(0.5)s_x}{\hat{\beta}_x}$$

where s_x is the base scale for the covariate x as used in the analysis (e.g., 1 m/s for wind speed, or 100 m for distance from river), and $\hat{\beta}_x$ is the corresponding estimated regression coefficient (the ˆ denotes an estimated values as opposed to a know quantity). A confidence interval can be calculated using the same equation, although where the estimated lower and upper limits for β_x are used in place of $\hat{\beta}_x$.

Table D.1: Change in the value of a covariate to halve the predicted number of bat calls per hour. Positive and negative values indicate that an increase, or decrease, in the covariate value is required, respectively. Values in parentheses indicate 95% confidence intervals.

Covariate	Period		Nightly		Hourly	
WindSpeed (m/s)	1.24	(0.76, 3.35)	4.38	(2.74, 11.01)	8.16	(4.41, 54.74)
VegHeightMax (m)	-8.00	(-76.99, -4.22)	-5.90	(-18.79, -3.50)	-5.26	(-14.41, -3.22)
DistanceTrack (m)	729.60	(395.80, 4,657.39)	591.23	(348.15, 1,959.01)	515.32	(317.57, 1,365.86)
DistancePond (m)	-1,923.38	(-Inf, -659.02)	-2,019.32	(-Inf, -663.91)	-1,524.66	(-Inf, -590.49)
DistanceRiver (m)	157.08	(89.42, 645.40)	142.11	(82.57, 509.70)	152.24	(84.82, 742.31)
Elevation (m)	-39.64	(-80.35, -26.31)	-43.66	(-100.92, -27.86)	-44.08	(-107.53, -27.72)
Temp (C)					-2.70	(-3.41, -2.24)

Table D.2: Change in the value of a covariate to halve the predicted odds of bat call presence per hour. Positive and negative values indicate that an increase, or decrease, in the covariate value is required, respectively. Values in parentheses indicate 95% confidence intervals.

Covariate	Period		Nightly		Hourly	
WindSpeed (m/s)	3.97	(1.62, Inf)	3.75	(2.72, 5.99)	7.19	(4.48, 18.20)
VegHeightMax (m)	-7.24	(-17.76, -4.41)	-9.91	(-35.45, -5.76)	-8.82	(-29.28, -5.20)
DistanceTrack (m)	928.31	(543.96, 2,741.89)	836.25	(511.10, 2,298.61)	738.39	(460.14, 1,867.93)
DistancePond (m)	-11,377.55	(-Inf, -1,326.59)	-4,748.84	(-Inf, -1,164.81)	-3,839.64	(-Inf, -1,046.45)
DistanceRiver (m)	190.72	(116.18, 487.91)	205.85	(123.18, 625.91)	186.43	(112.60, 541.35)
Elevation (m)	-51.47	(-94.68, -34.39)	-53.63	(-101.86, -36.40)	-49.55	(-92.79, -33.80)
Temp (C)					-3.54	(-4.50, -2.92)

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