Supplementary Figures for “Exploring distribution, caste specific seasonality, and winter activity of three invasive wasps (Hymenoptera: Vespidae) in New Zealand using citizen science data”

Insectes Sociaux

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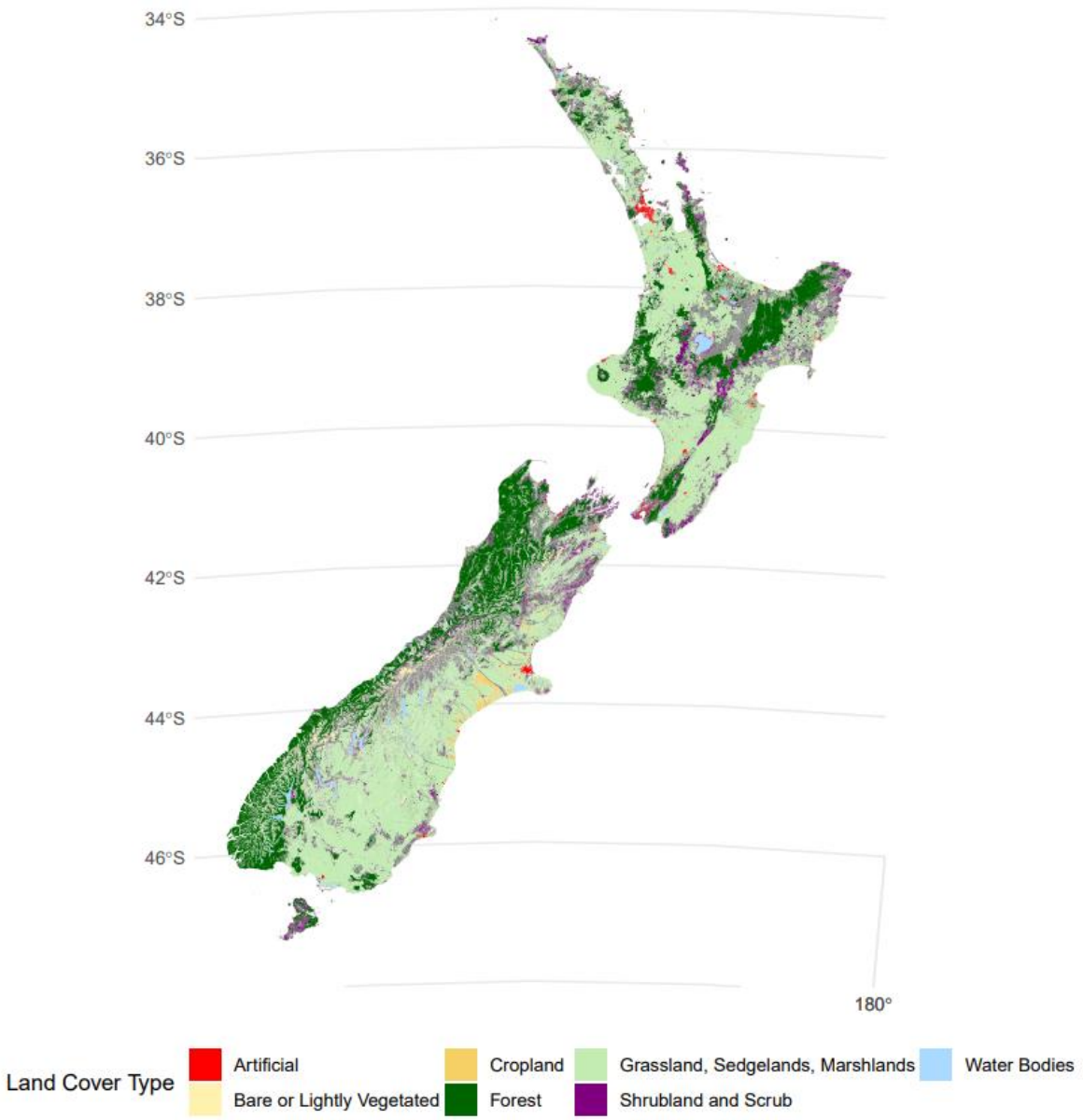
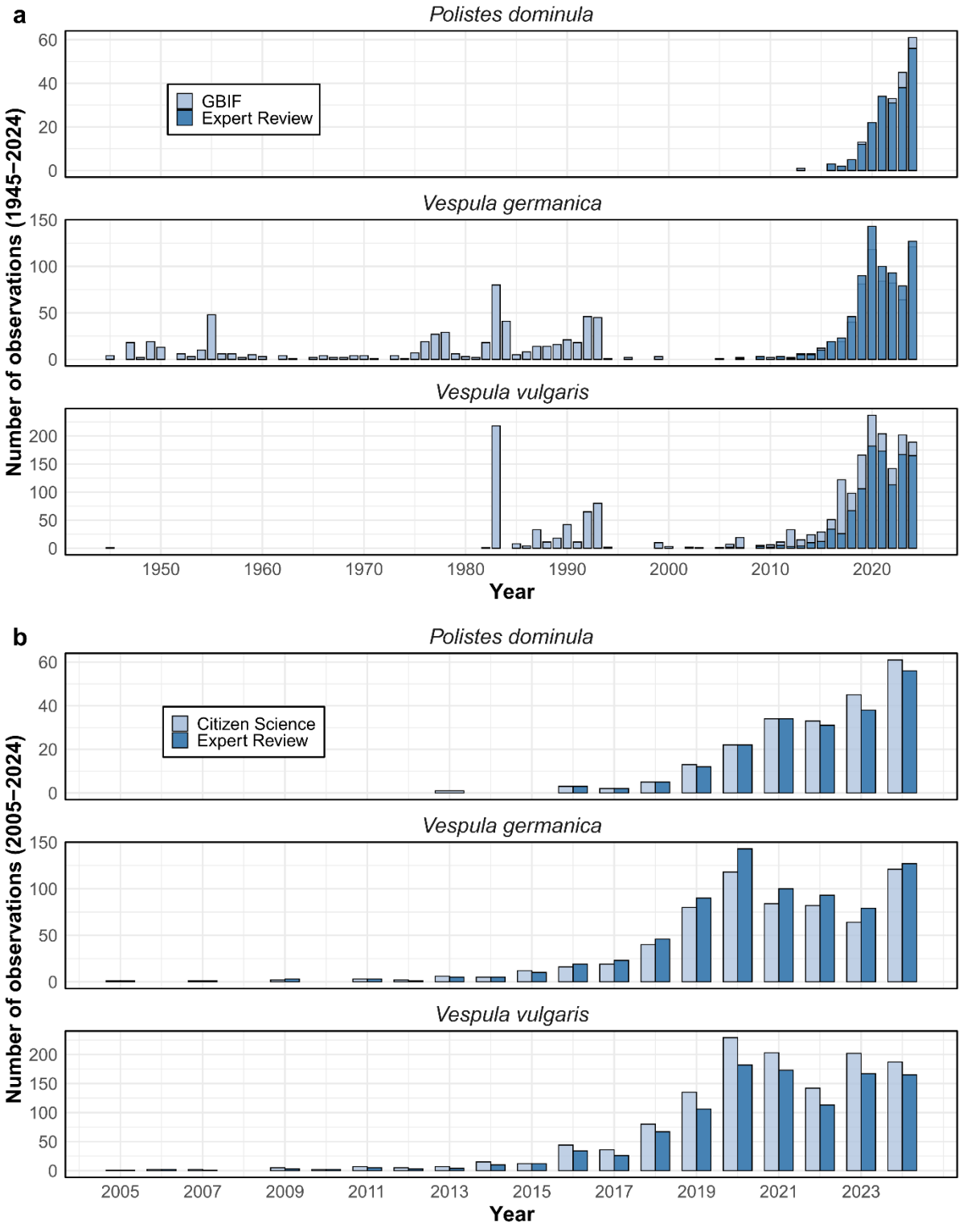


Supplementary Figure 1. Land cover type use in New Zealand. Each land cover category is represented by the following colours: Artificial (red), Bare/Lightly Vegetated (pale yellow), Water bodies (blue), Cropland (yellow), Grassland (pale green), Shrubland (purple), and Forest (dark green). Grey areas on the map denote regions either lacking land cover information or areas where the land cover did not fall into the aforementioned categories. This map uses land cover polygons from the New Zealand Land Cover Database (LCDB), version 5.0, which categorised land cover into broader habitat types based on LCDB classification codes. In this classification, 'Artificial' refers to urban landscapes, including settlements, urban parkland, and transport infrastructure, whereas 'Cropland' covers areas used for cultivation, as well as vineyards and orchards. Wasp observation coordinates were overlaid on the land cover polygons to calculate the percentage of land cover usage for *Polistes dominula*, *Vespula germanica*, and *Vespula vulgaris*, as shown in Figure 6.



Supplementary Figure 2. Annual wasp observations in New Zealand for *Polistes dominula*, *Vespula germanica*, and *Vespula vulgaris*. (a) Comparison of 3554 citizen-sourced records submitted through GBIF (light blue) with 2028 expert-validated records (dark blue), dating from 1945 to 2024. The original GBIF dataset highlights the approximate dates of species introduction in New Zealand: *V. germanica* in the 1940s, *V. vulgaris* in the 1980s, and *P. dominula* in the 2010s. (b) Comparison of 2190 image-based citizen-sourced observations prior to expert review (light blue), with 2028 expert-validated records (dark blue). The image-based observations, which were reviewed by experts, spanning from 2005 to 2024, reflected the typical years of activity of citizen-sourced online datasets.

Supplementary Table 1. Results of generalised linear models (GLMs) used to model seasonal and caste-based differences in wasp observations. Models were initially fitted separately for each species with a Poisson error distribution. Overdispersion was assessed by calculating the ratio of the Pearson Chi-squared statistic to the residual degrees of freedom (Pearson χ^2/df). When this ratio exceeded 1.5, the models were refitted using a negative binomial distribution. Species, predictor variables, model estimates, standard errors, *z*-values, *p*-values (Pr(>|*z*|)), and significance levels were reported for each model. Rows in bold show the species and predictors for which statistically significant differences were found. Significance codes: *** $p < 0.001$; ** $p < 0.01$; * $p < 0.05$; . $p < 0.1$.

Species	Predictor	Estimate	Std. Error	*z* value	Pr(>|*z*|)	Significance
P. dominula	(Intercept)	0.69314718	0.4352946	1.59236335	0.1113031	
P. dominula	casteMale	-19.995732	5442.4598	-0.003674	0.9970686	
P. dominula	**seasonSpring**	**1.9218126**	**0.4865042**	**3.95024845**	**7.81E-05**	***
P. dominula	**seasonSummer**	**2.61495978**	**0.4738051**	**5.51906242**	**3.41E-08**	***
P. dominula	**seasonAutumn**	**2.03688193**	**0.4837719**	**4.21041798**	**2.55E-05**	***
P. dominula	casteMale:seasonSpring	-1.9218126	7696.8005	-0.0002497	0.9998008	
P. dominula	casteMale:seasonSummer	16.9753074	5442.4598	0.00311905	0.9975114	
P. dominula	casteMale:seasonAutumn	19.5343867	5442.4598	0.00358926	0.9971362	
V. germanica	**(Intercept)**	**2.7080502**	**0.2837616**	**9.54339945**	**1.38E-21**	***
V. germanica	**casteMale**	**-3.8066625**	**1.0671547**	**-3.5671142**	**0.0003609**	***
V. germanica	**casteQueen**	**-1.5040774**	**0.4886912**	**-3.0777667**	**0.0020856**	**
V. germanica	seasonSpring	0.67067432	0.3875341	1.73062007	0.0835196	.
V. germanica	**seasonSummer**	**1.33500107**	**0.3803512**	**3.5099171**	**0.0004482**	***
V. germanica	**seasonAutumn**	**2.02814825**	**0.3764878**	**5.38702305**	**7.16E-08**	***
V. germanica	casteMale:seasonSpring	0.93876359	1.2111067	0.7751287	0.4382636	
V. germanica	casteQueen:seasonSpring	-1.3638215	0.7528476	-1.8115505	0.0700557	.
V. germanica	casteMale:seasonSummer	0.74444047	1.1773971	0.63227648	0.5272062	
V. germanica	**casteQueen:seasonSummer**	**-2.2512918**	**0.7818336**	**-2.8795023**	**0.003983**	**
V. germanica	**casteMale:seasonAutumn**	**2.24851787**	**1.1279312**	**1.99348852**	**0.046208**	*
V. germanica	**casteQueen:seasonAutumn**	**-2.944439**	**0.7799615**	**-3.7751083**	**0.0001599**	***
V. vulgaris	**(Intercept)**	**2.99573227**	**0.282419**	**10.6074036**	**2.75E-26**	***
V. vulgaris	**casteMale**	**-2.7080502**	**0.6267809**	**-4.320569**	**1.56E-05**	***
V. vulgaris	casteQueen	-0.6603574	0.4184643	-1.5780494	0.1145543	
V. vulgaris	seasonSpring	0.725937	0.3884827	1.8686468	0.061672	.
V. vulgaris	**seasonSummer**	**1.33060546**	**0.3837442**	**3.46742833**	**0.0005255**	***

V. vulgaris	**seasonAutumn**	**2.15948425**	**0.3804962**	**5.67544175**	**1.38E-08**	***
V. vulgaris	casteMale:seasonSpring	-19.316204	3301.0188	-0.0058516	0.9953311	
V. vulgaris	**casteQueen:seasonSpring**	**-1.2695524**	**0.6040862**	**-2.1016082**	**0.0355876**	*
V. vulgaris	**casteMale:seasonSummer**	**-2.7168998**	**1.2342801**	**-2.2012021**	**0.0277217**	*
V. vulgaris	**casteQueen:seasonSummer**	**-3.6659804**	**0.7993989**	**-4.5859211**	**4.52E-06**	***
V. vulgaris	casteMale:seasonAutumn	0.7717095	0.7309572	1.05575203	0.2910815	
V. vulgaris	**casteQueen:seasonAutumn**	**-2.7030997**	**0.5989813**	**-4.5128278**	**6.40E-06**	***