



Supplementary Information for

Climate-induced phenological shifts in a Batesian mimicry complex

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This PDF file includes:

Supplementary text

Figs. S1 to S10

Tables S1 to S3

References for SI reference citations

Supplementary Information Text

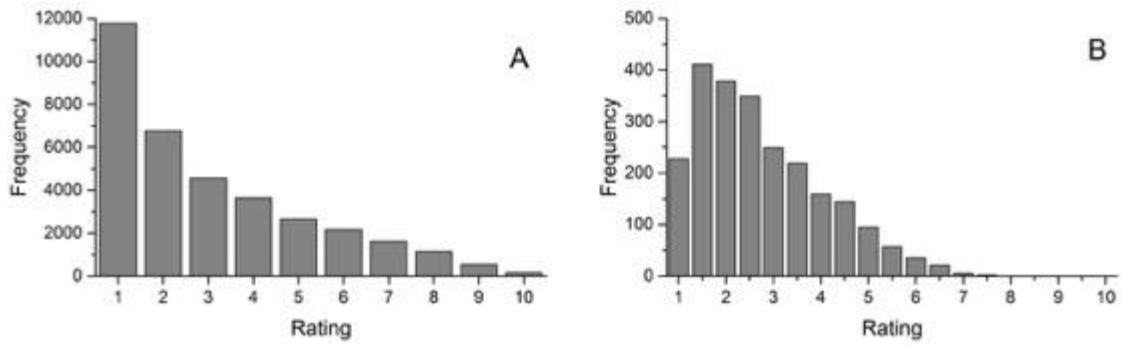


Fig. S1. Frequency distribution of (A) raw ratings across 30,300 comparisons, and (B) mean pairwise similarity ratings for 2,532 pairs of Syrphidae and Hymenoptera, where 1=not at all similar and 10=identical.

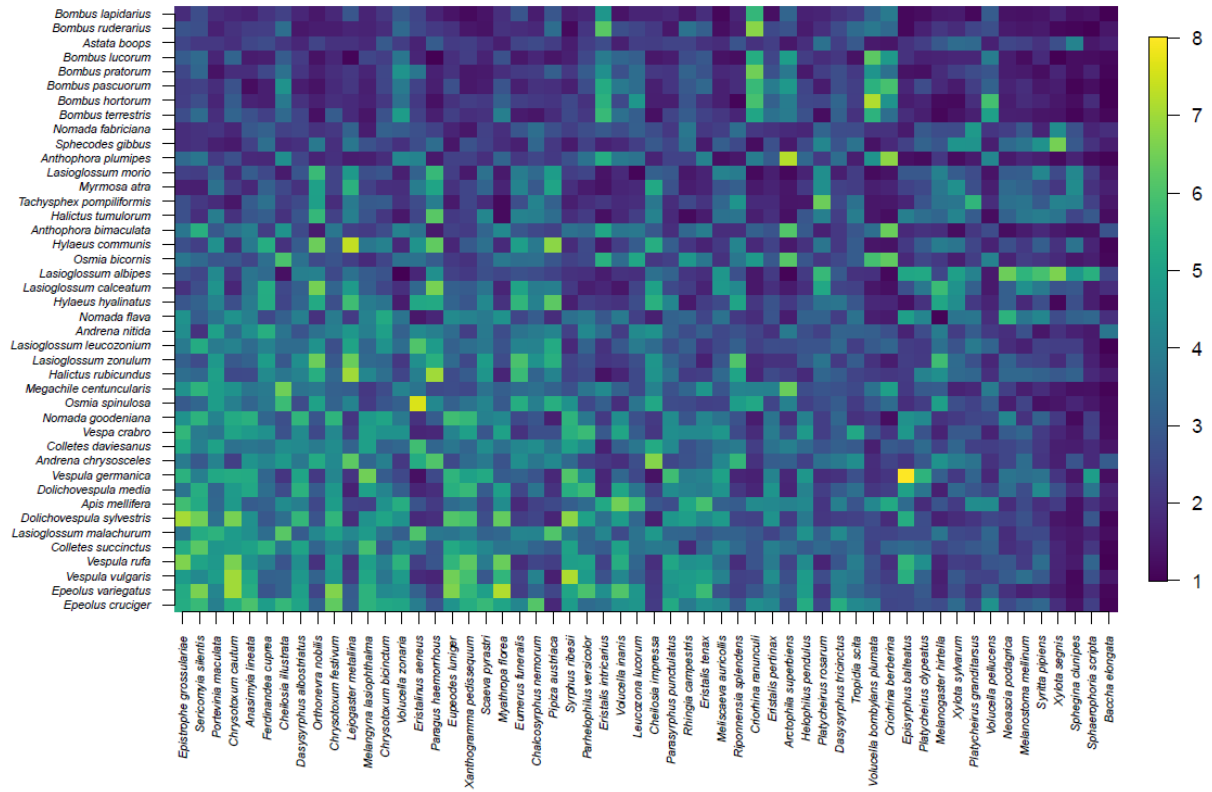


Fig. S2. Heat map of mimetic ratings between 56 Syrphidae and 42 Hymenoptera with species labelled. Colours indicate the mean similarity rating for each pair.

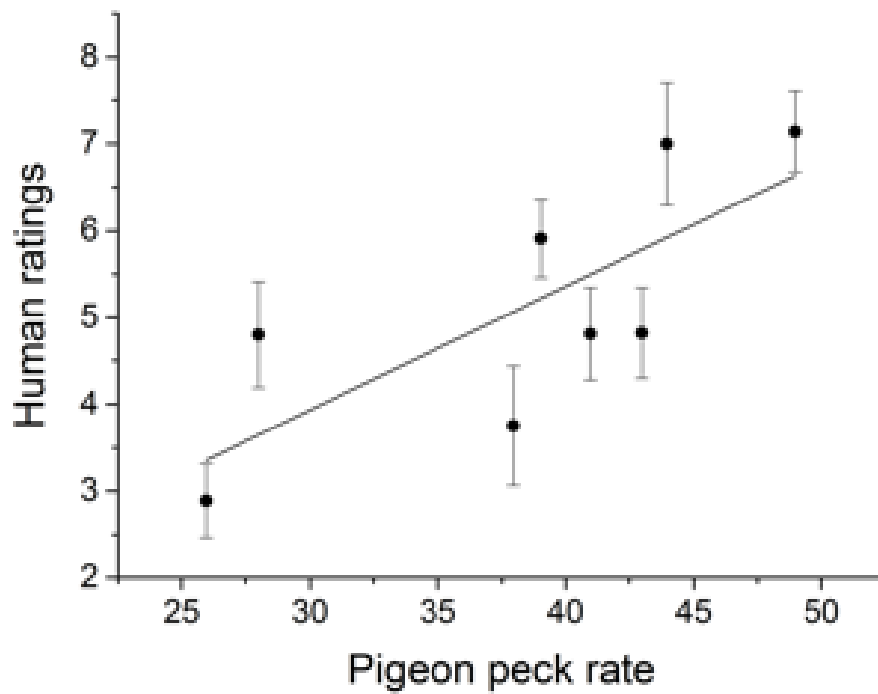


Fig. S3. Comparison of pigeon peck rate (a proxy for pigeon judgements of similarity between images from (1)) and independent human ratings of similarity between different images for eight species of Syrphidae and *Vespula vulgaris* from the present study. Error bars are SE associated with the human ratings.

Table S1. Lists of Syrphidae (n=56) and Hymenoptera (n=42) species used in an online citizen science experiment.

Syrphidae		Hymenoptera	
<i>Anasimyia lineata</i>	<i>Meliscaeva auricollis</i>	<i>Andrena nitida</i>	<i>Lasioglossum zonulum</i>
<i>Arctophila superbiens</i>	<i>Myathropa florea</i>	<i>Andrena chrysoseles</i>	<i>Megachile centuncularis</i>
<i>Baccha elongata</i>	<i>Neoascia podagrica</i>	<i>Anthophora bimaculata</i>	<i>Myrmosa atra</i>
<i>Chalcosyrphus nemorum</i>	<i>Orthonevra nobilis</i>	<i>Anthophora plumipes</i>	<i>Nomada fabriciana</i>
<i>Cheilosia illustrata</i>	<i>Paragus haemorrhous</i>	<i>Apis mellifera</i>	<i>Nomada flava</i>
<i>Cheilosia impressa</i>	<i>Parasyrphus punctulatus</i>	<i>Astata boops</i>	<i>Nomada goodeniana</i>
<i>Chrysotoxum bicinctum</i>	<i>Parhelophilus versicolor</i>	<i>Bombus hortorum</i>	<i>Osmia spinulosa</i>
<i>Chrysotoxum cautum</i>	<i>Pipiza austriaca</i>	<i>Bombus lapidarius</i>	<i>Osmia bicornis</i>
<i>Chrysotoxum festivum</i>	<i>Platycheirus clypeatus</i>	<i>Bombus lucorum</i>	<i>Sphecodes gibbus</i>
<i>Criorhina berberina</i>	<i>Platycheirus granditarsus</i>	<i>Bombus pascuorum</i>	<i>Tachysphex pompiliformis</i>
<i>Criorhina ranunculi</i>	<i>Platycheirus rosarum</i>	<i>Bombus pratorum</i>	<i>Vespa crabro</i>
<i>Dasysyrphus albostrigatus</i>	<i>Portevinia maculata</i>	<i>Bombus terrestris</i>	<i>Vespula germanica</i>
<i>Dasysyrphus tricinctus</i>	<i>Rhingia campestris</i>	<i>Bombus ruderarius</i>	<i>Vespula rufa</i>
<i>Epistrophe grossulariae</i>	<i>Riponnensia splendens</i>	<i>Colletes daviesanus</i>	<i>Vespula vulgaris</i>
<i>Episyrphus balteatus</i>	<i>Scaeva pyrastris</i>	<i>Colletes succinctus</i>	
<i>Eristalinus aeneus</i>	<i>Sericomyia silentis</i>	<i>Dolichovespula media</i>	
<i>Eristalis pertinax</i>	<i>Sphaerophoria scripta</i>	<i>Dolichovespula sylvestris</i>	
<i>Eristalis tenax</i>	<i>Sphegina clunipes</i>	<i>Epeolus cruciger</i>	
<i>Eristalis intricarius</i>	<i>Syrirta pipiens</i>	<i>Epeolus variegatus</i>	
<i>Eumerus funeralis</i>	<i>Syrphus ribesii</i>	<i>Halictus rubicundus</i>	
<i>Eupeodes luniger</i>	<i>Tropidia scita</i>	<i>Halictus tumulorum</i>	
<i>Ferdinandea cuprea</i>	<i>Volucella bombylans plumata</i>	<i>Hylaeus communis</i>	
<i>Helophilus pendulus</i>	<i>Volucella inanis</i>	<i>Hylaeus hyalinatus</i>	
<i>Lejogaster metallina</i>	<i>Volucella pellucens</i>	<i>Lasioglossum albipes</i>	
<i>Leucozonia lucorum</i>	<i>Volucella zonaria</i>	<i>Lasioglossum calceatum</i>	
<i>Melangyna lasiophthalma</i>	<i>Xanthogramma pedissequum</i>	<i>Lasioglossum leucozonium</i>	
<i>Melanogaster hirtella</i>	<i>Xylota segnis</i>	<i>Lasioglossum malachurum</i>	
<i>Melanostoma mellinum</i>	<i>Xylota sylvarum</i>	<i>Lasioglossum morio</i>	

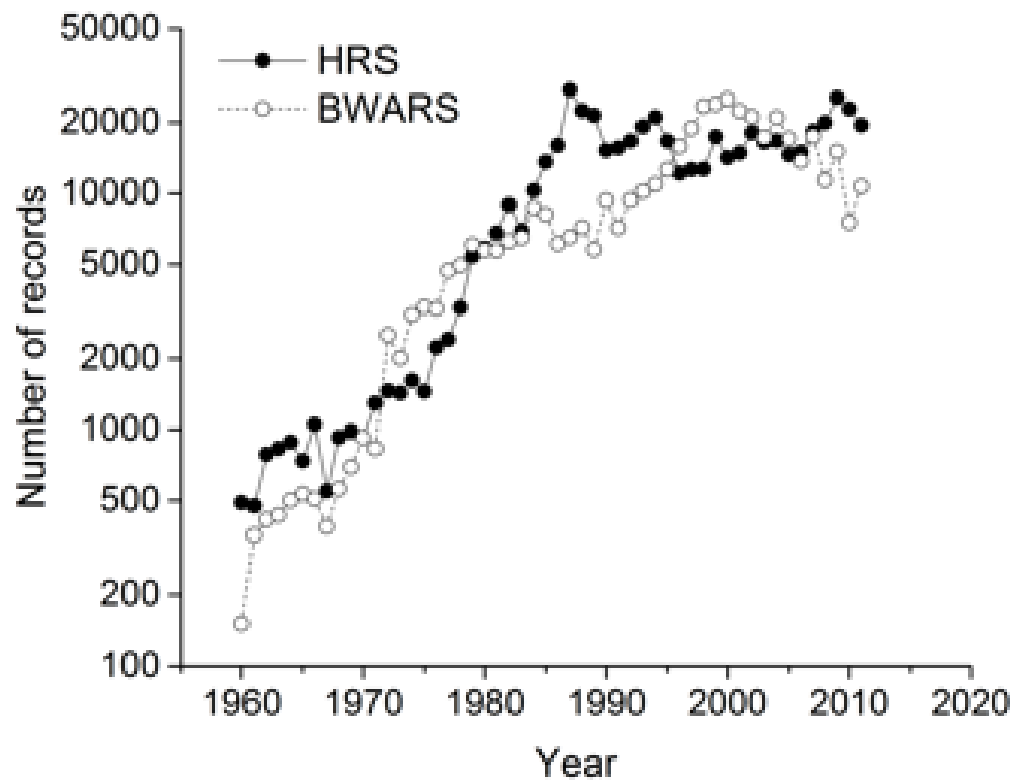


Fig. S4. Temporal variation in the number of records per year contained within the Hoverfly Recording Scheme (grey) and the Bees, Wasps and Ants Recording Scheme (black).

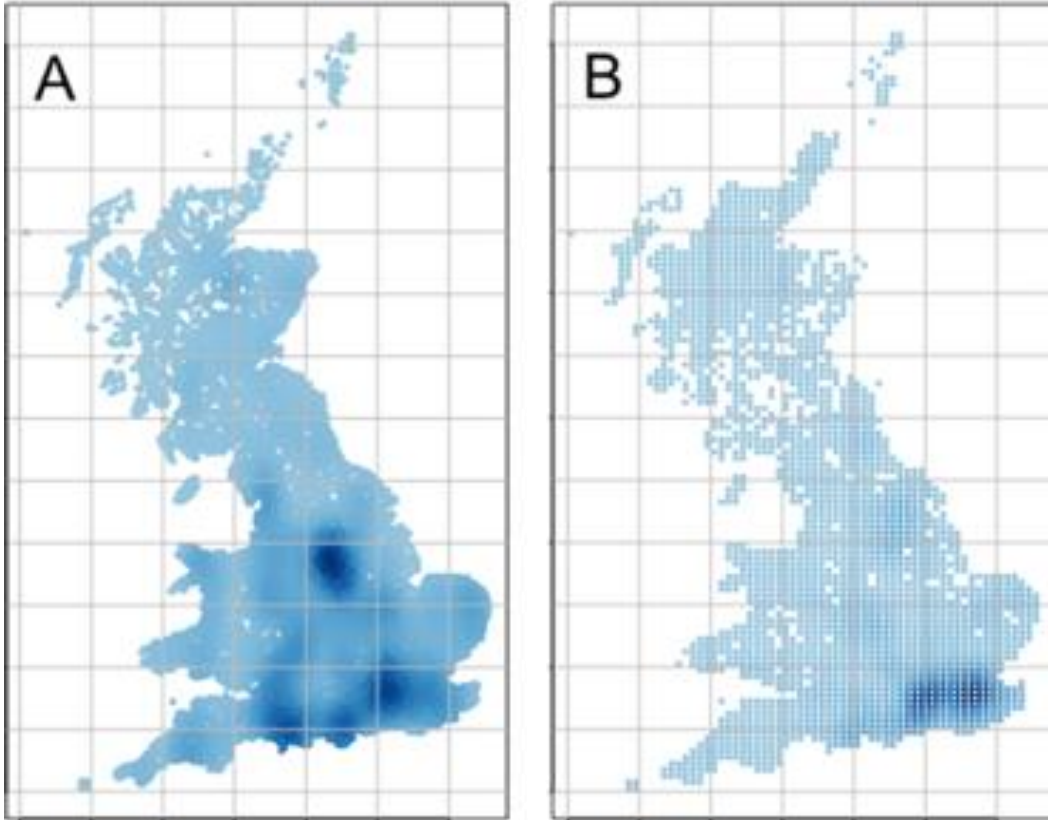


Fig. S5. Spatial distribution of records showing (A) Hoverfly Recording Scheme and (B) Bees, Wasps and Ants Recording Scheme data from 1960-2014.

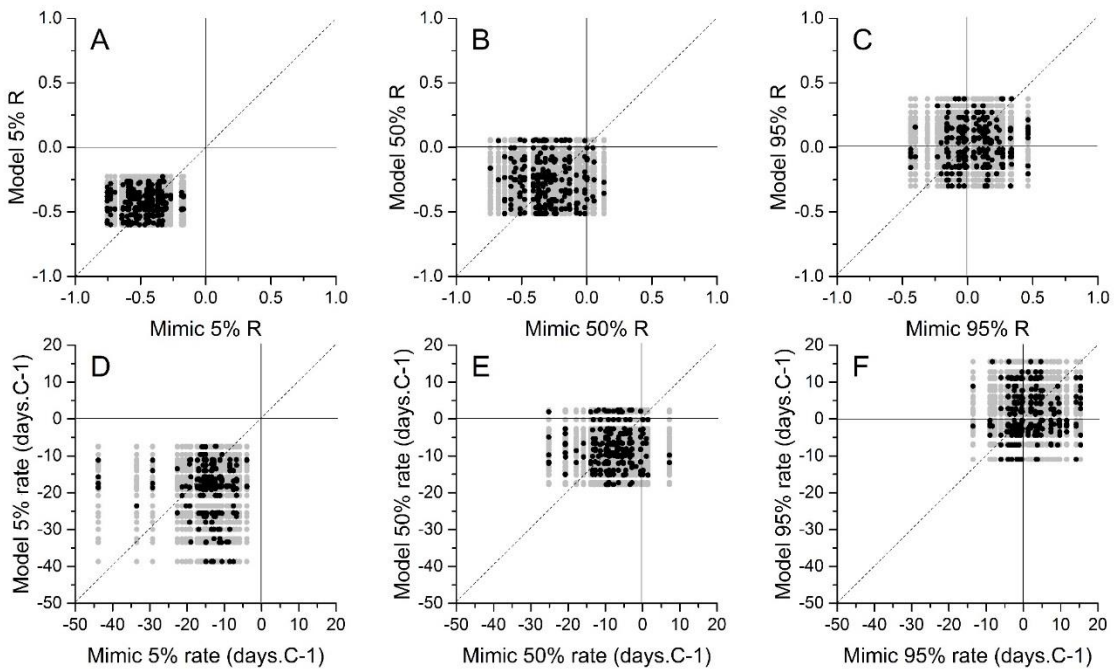


Fig. S6. Comparisons of the strength of the correlation between phenology and temperature and the rate of change in phenology with temperature between Hymenoptera and Syrphidae in parts of the flight period: 5% flight dates (A,D), 50% flight dates (B,E) and 95% flight dates (C,F). In each plot, grey points show all possible pairwise combinations of Hymenoptera and Syrphidae regardless of mimetic relationships, while black points show the high quality mimics defined from the online experiment (see text for details). Dotted diagonal line is a 1:1 relationship, which would be expected if models and mimics were changing phenology consistently (A, B, C) or at the same rate (D, E, F).

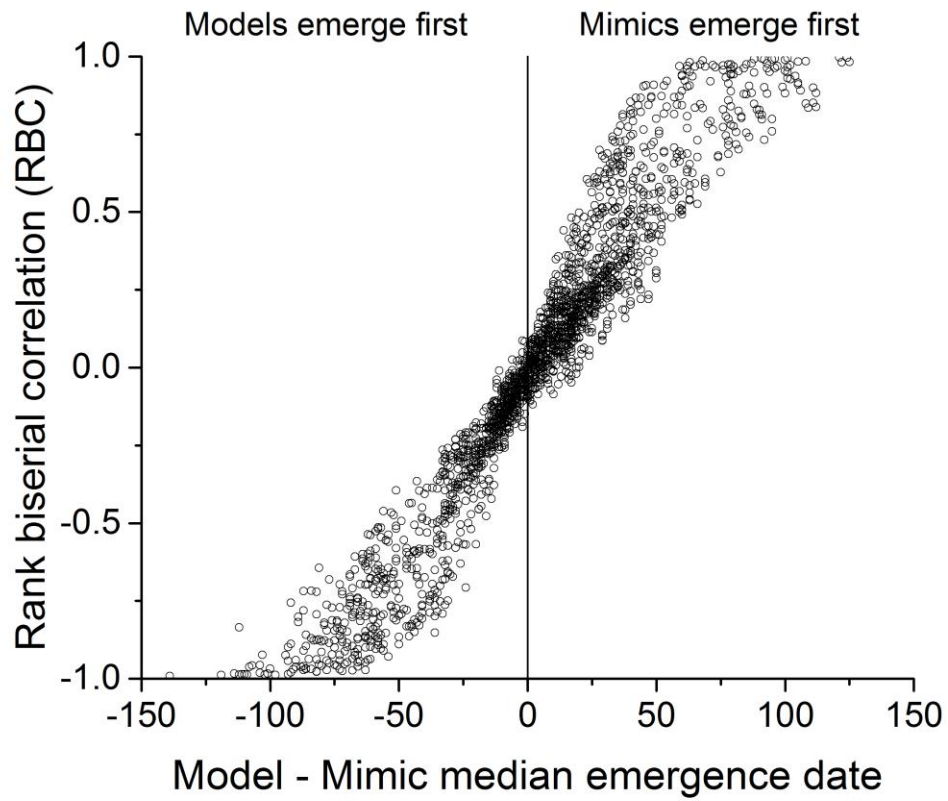


Fig. S7. Relationship between the difference in the median flight date from biological records and the rank biserial correlation (RBC) as a measure of phenological synchrony based on 2,352 model-mimic pairs from Study 1.

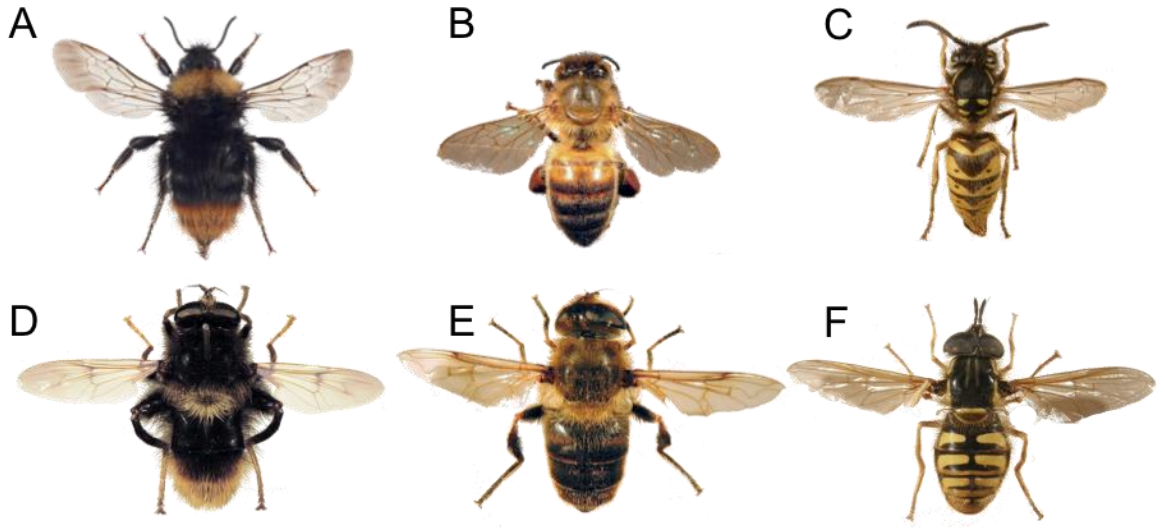


Fig. S8. Three pairs of models and mimics used as stimuli for the behavioural experiment: (A) *Bombus pratorum* and (D) *Criorhina ranunculi*, (B) *Apis mellifera* and (E) *Eristalis tenax*, and (C) *Vespula vulgaris* and (F) *Chrysotoxum cautum*. Fig. S8A courtesy of Arnstein Staverløkk (Norwegian Institute for Nature Research, Trondheim, Norway). Fig. S8B–F courtesy of Steven Falk (photographer).

Table S2. Examples of the order of presentation of stimuli in the behavioural experiment to give a rank biserial correlation of 0.677 (the mean from the distribution of RBCs generated for the experiment – see text for details). In each case, “A” corresponds to the mimic and “B” corresponds to the model insect image. Note that “mimic-first” and “model-first” involve a degree of overlap. The overlap was determined by increasing the probability of occurrence of the second species from 0-100% over the 50 time steps (i.e. by 2% each time step) to produce a single phenological pattern for each of mimic-first and model-first. The random scenario was created using the same principle, but with 50% probability of each species at each time step.

Mimic-first	A	A	A	B	A	A	A	B	B	A	A	B	A	A	B	A	A	A	B	A	A	A	B	A	B	A	B	B	B	B	B	B	A	B	B	B	B	B	B	B	B	B	B	B	B	B	B	B			
Model-first	B	B	B	B	B	B	B	B	B	B	B	B	B	A	B	B	B	B	A	B	B	B	B	B	A	B	A	B	A	A	A	A	B	B	A	A	B	A	A	B	A	A	B	A	A	B	A	A	A	A	A
Random	B	B	A	B	B	A	B	B	B	A	A	B	B	A	A	A	A	B	B	B	A	A	B	B	A	A	B	A	A	A	A	A	A	B	A	A	A	A	B	B	A	A	B	B	A	B	A	B	B	B	

Table S3. Consequences of phenological scenarios (compared against the model-first scenario as a reference level) for mimic and model predation rates and predator score (based on the numbers of edible mimics and inedible models consumed).

Response	Predictor	Estimate	SE	z	P
Mimic predation rate	(Intercept)	1.526	0.331	4.608	<0.001
	Trial number	0.049	0.005	9.811	<0.001
	Scenario: Mimic1st	0.410	0.172	2.381	0.017
	Scenario: Random	-0.465	0.151	-3.073	0.002
Model predation rate	(Intercept)	-1.715	0.199	-8.633	<0.001
	Trial number	-0.057	0.005	-11.669	<0.001
	Scenario: Mimic1st	1.110	0.159	6.983	<0.001
	Scenario: Random	0.446	0.146	3.050	0.002
Predator score	(Intercept)	3.708	0.047	78.186	<0.001
	Scenario: Mimic1st	-0.017	0.033	-0.529	0.597
	Scenario: Random	-0.069	0.034	-2.055	0.040



Fig. S9. Example screen from the experiment in Study 3, showing *Criorhina ranunculi*.

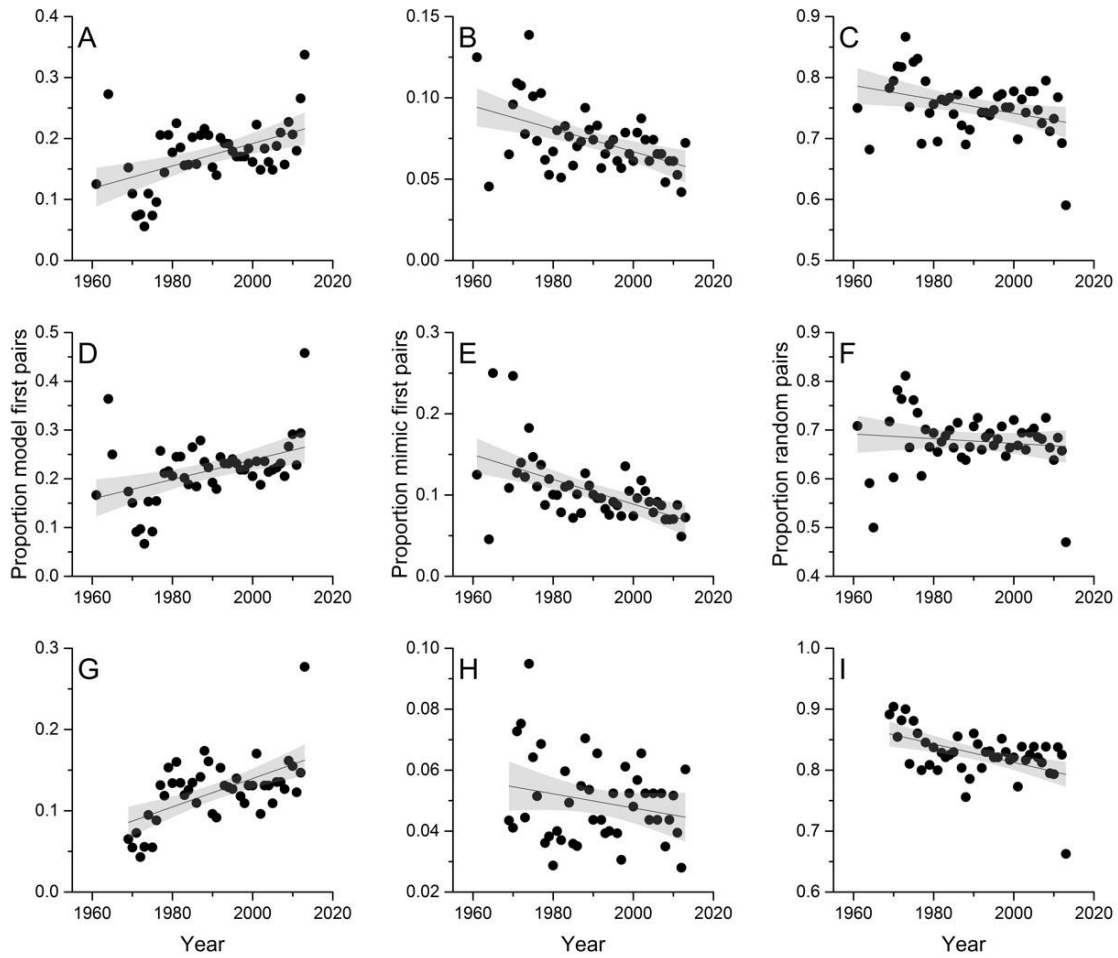


Fig. S10. Sensitivity analysis showing the proportion of 2,352 model-mimic pairs defined as each of three phenological scenarios (model-first, mimic-first, random) through time. The different panels show the effects of varying the threshold for clarification into each of the three categories: (A-C) mean value from the RBC distribution, (D-F) mean threshold - 1SD, and (G-I) mean threshold + 1SD.

References

1. Bain RS, Rashed A, Cowper VJ, Gilbert FS, & Sherratt TN (2007) The key mimetic features of hoverflies through avian eyes. *Proceedings of the Royal Society: Series B (Biological Sciences)* 274:1949-1954.