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Supplementary Information for

Climate-induced phenological shifts in a Batesian mimicry complex

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Supplementary Information Text

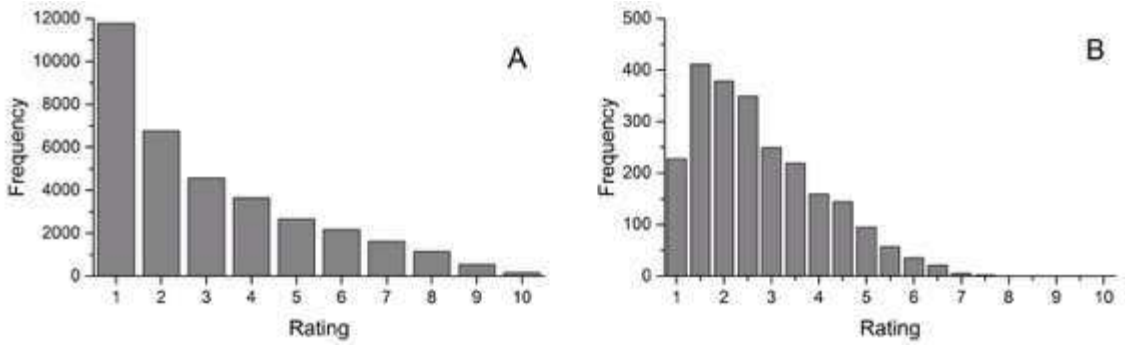

Fig. S1. Frequency distribution of (A) raw ratings across 30,300 comparisons, and (B) mean pairwise similarity ratings for 2,532 pairs of Syrphidae and Hymenoptera, where 1=not at all similar and 10=identical.

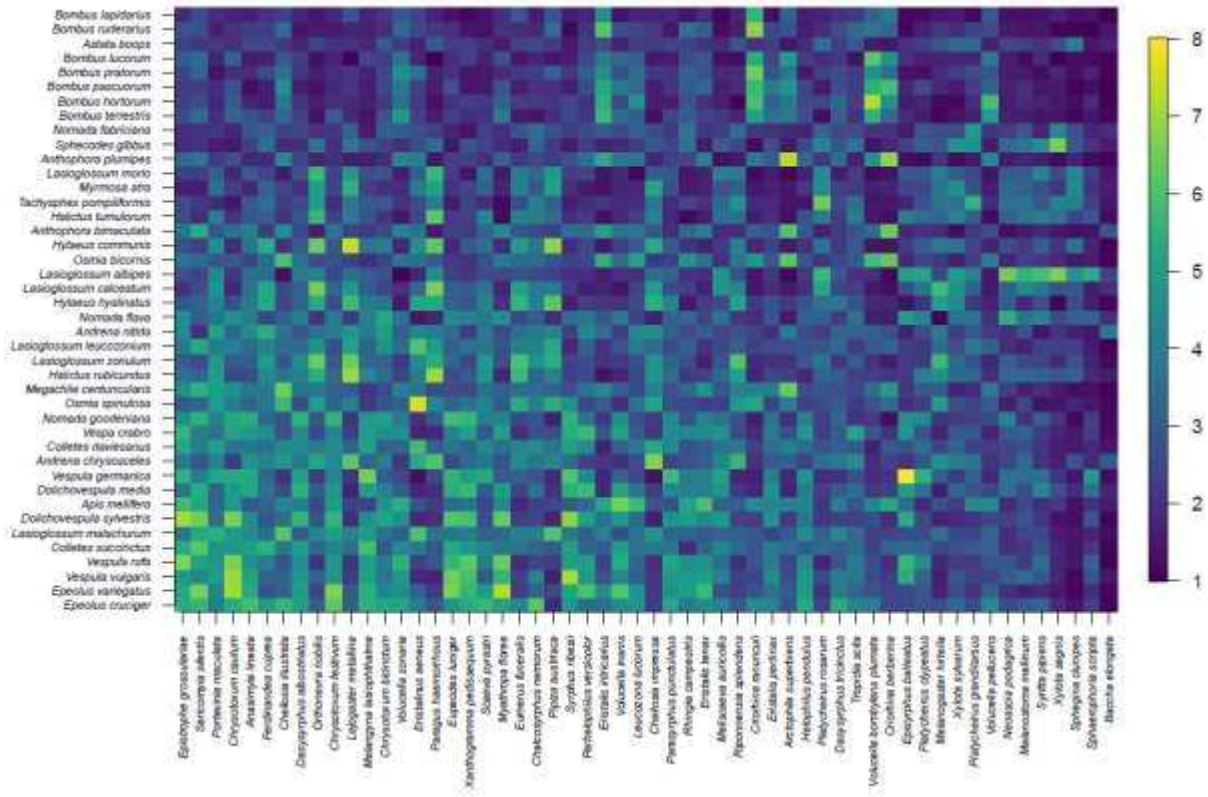

Fig. S2. Heat map of mimetic ratings between 56 Syrphidae and 42 Hymenoptera with species labelled. Colours indicate the mean similarity rating for each pair.

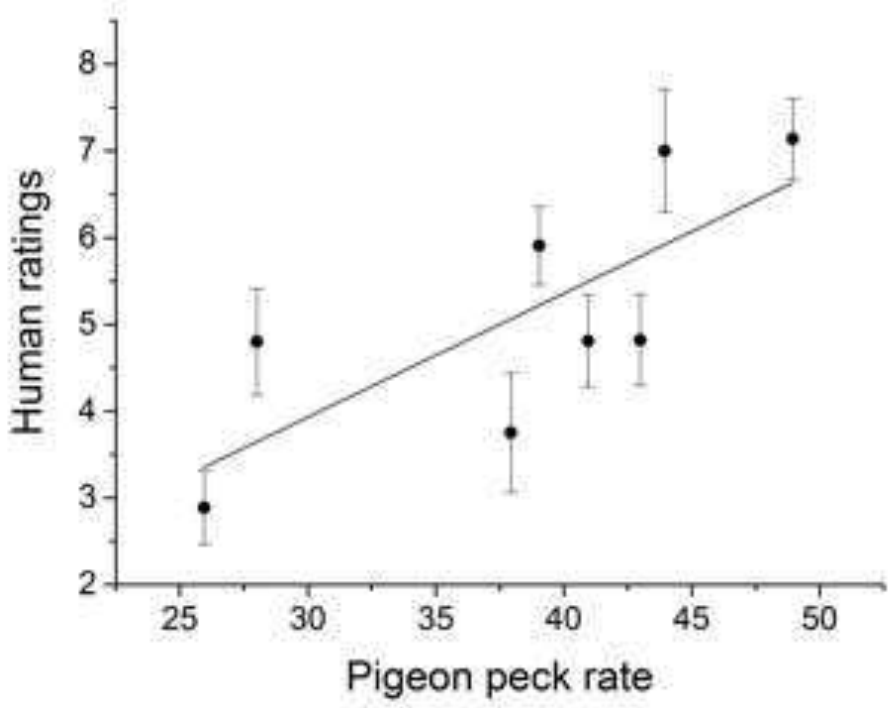

Fig. S3. Comparison of pigeon peck rate (a proxy for pigeon judgements of similarity between images from (1)) and independent human ratings of similarity between different images for eight species of Syrphidae and Vespula vulgaris from the present study. Error bars are SE associated with the human ratings.

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

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

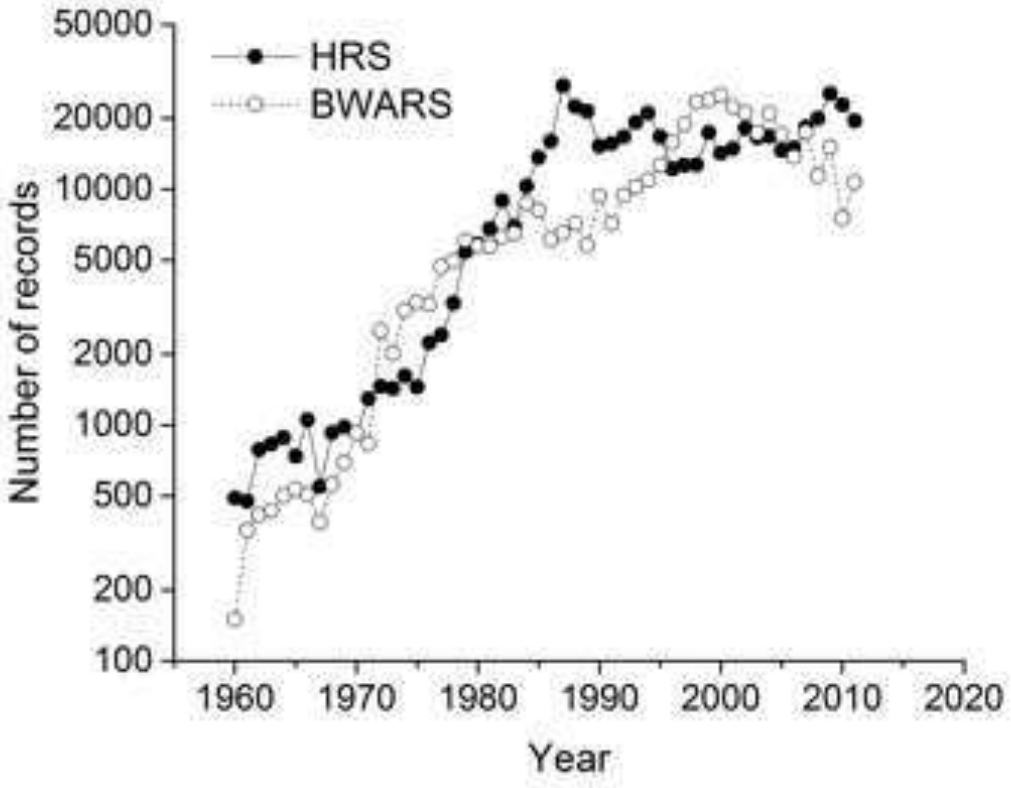

Fig. S4. Temporal variation in the number of records per year contained within the Hoverfly Recording Scheme (grey) and the Bees, Wasps and Ants Recording Scheme (black).

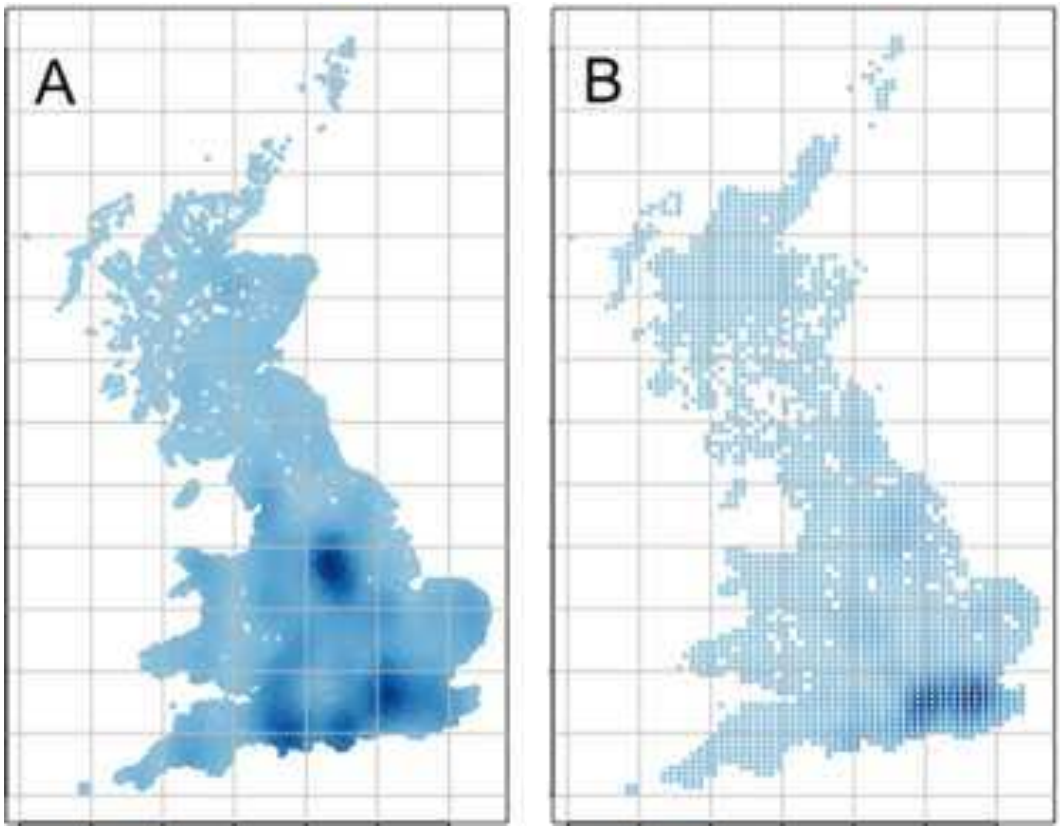

Fig. S5. Spatial distribution of records showing (A) Hoverfly Recording Scheme and (B) Bees, Wasps and Ants Recording Scheme data from 1960-2014.

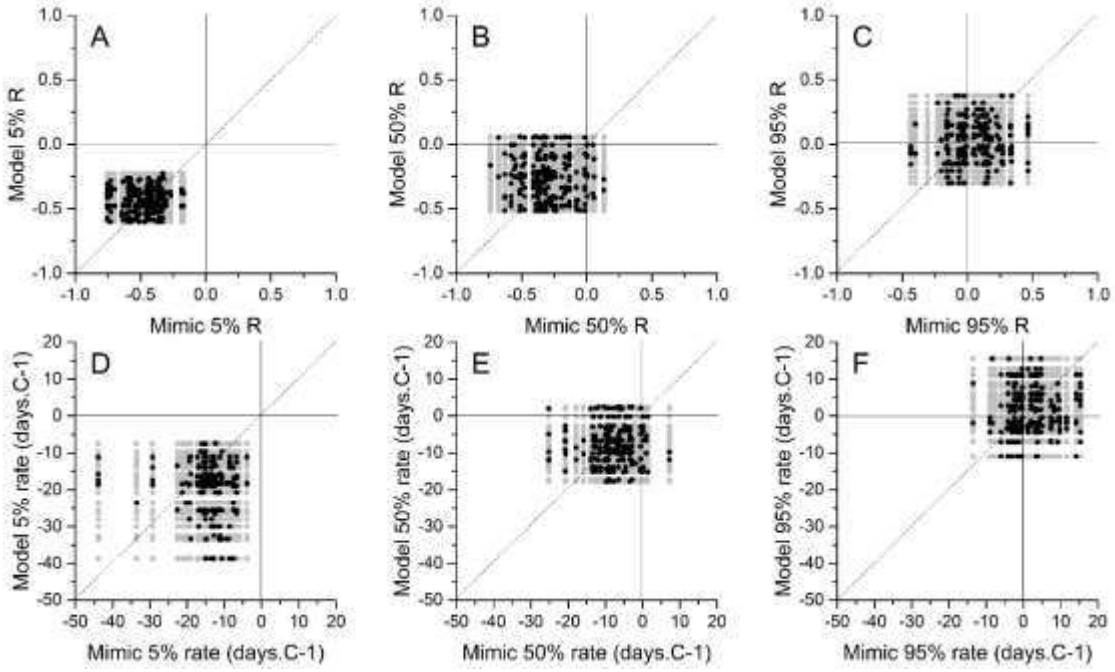

Fig. S6. Comparisons of the strength of the correlation between phenology and temperature and the rate of change in phenology with temperature between Hymenoptera and Syrphidae in parts of the flight period: 5% flight dates (A,D), 50% flight dates (B,E) and 95% flight dates (C,F). In each plot, grey 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).

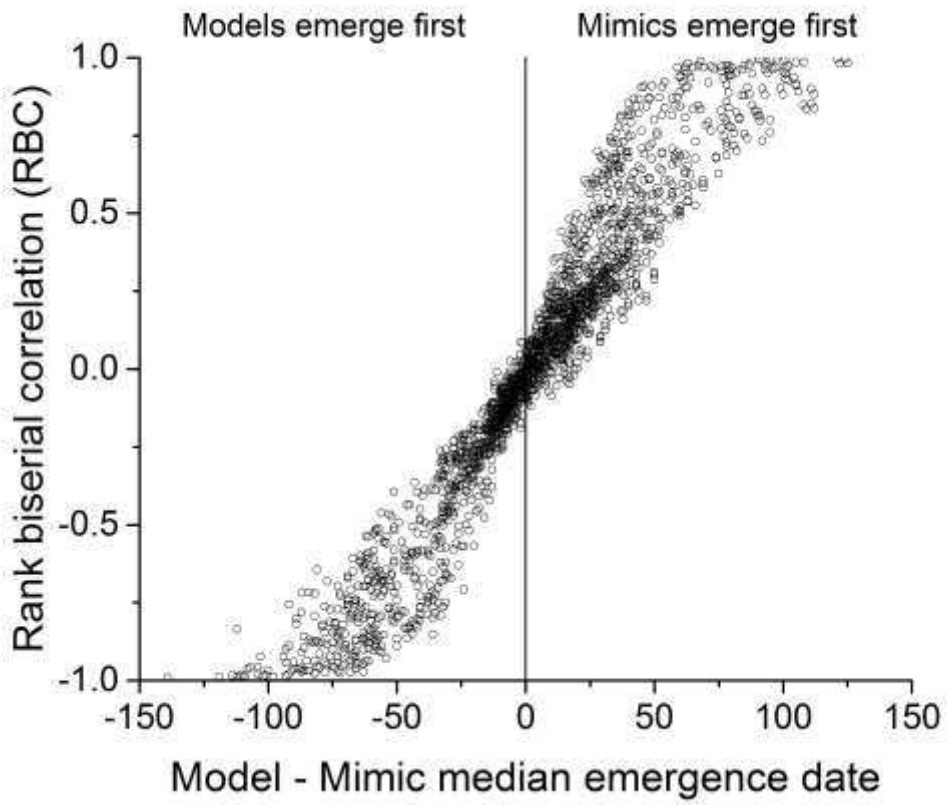

Fig. S7. Relationship between the difference in the median flight date from biological records and the rank biserial correlation (RBC) as a measure of phenological synchrony based on 2,352 model-mimic pairs from Study 1.

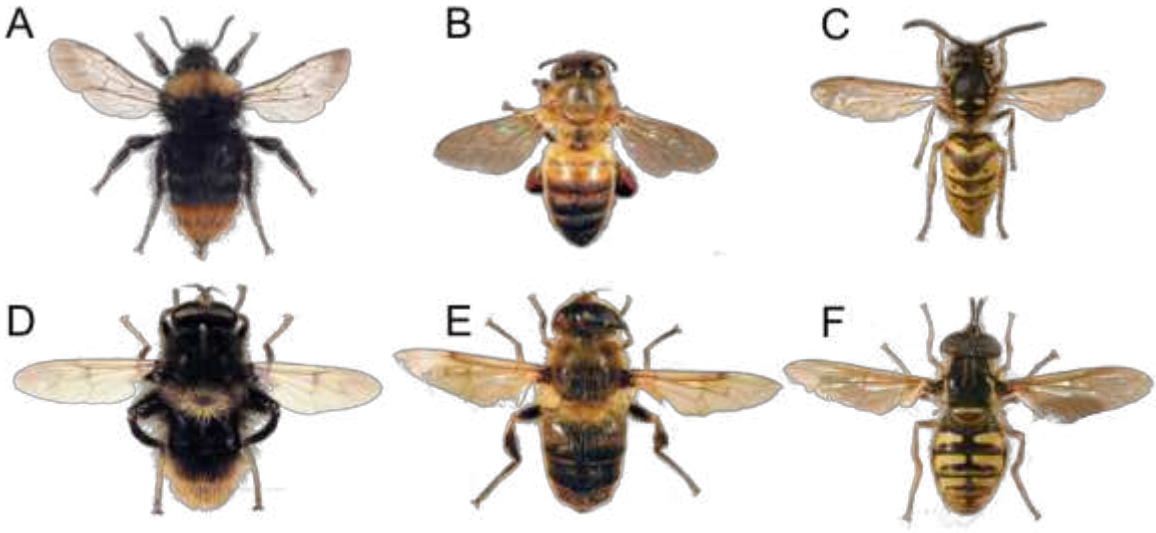

Fig. S8. Three pairs of models and mimics used as stimuli for the behavioural experiment: (A) Bombus pratorum and (D) Criorhina ranunculi, (B) Apis mellifera and (E) Eristalis tenax, and (C) Vespula vulgaris and (F) Chrysotoxum cautum. Images copyright Steven Falk and used with permission.

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	B	A	A	A	B	A	B	A	B	A	B	B	B	B	B	B	A	B	B	B	B	A	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	B	A	B	A	B	A	B	A	A	A	B	B	A	A	B	A	A	B	B	A	A	A	B	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	B	A	A	B	A	A	A	A	A	A	B	A	A	A	A	B	B	A	A	B	B	A	B	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.

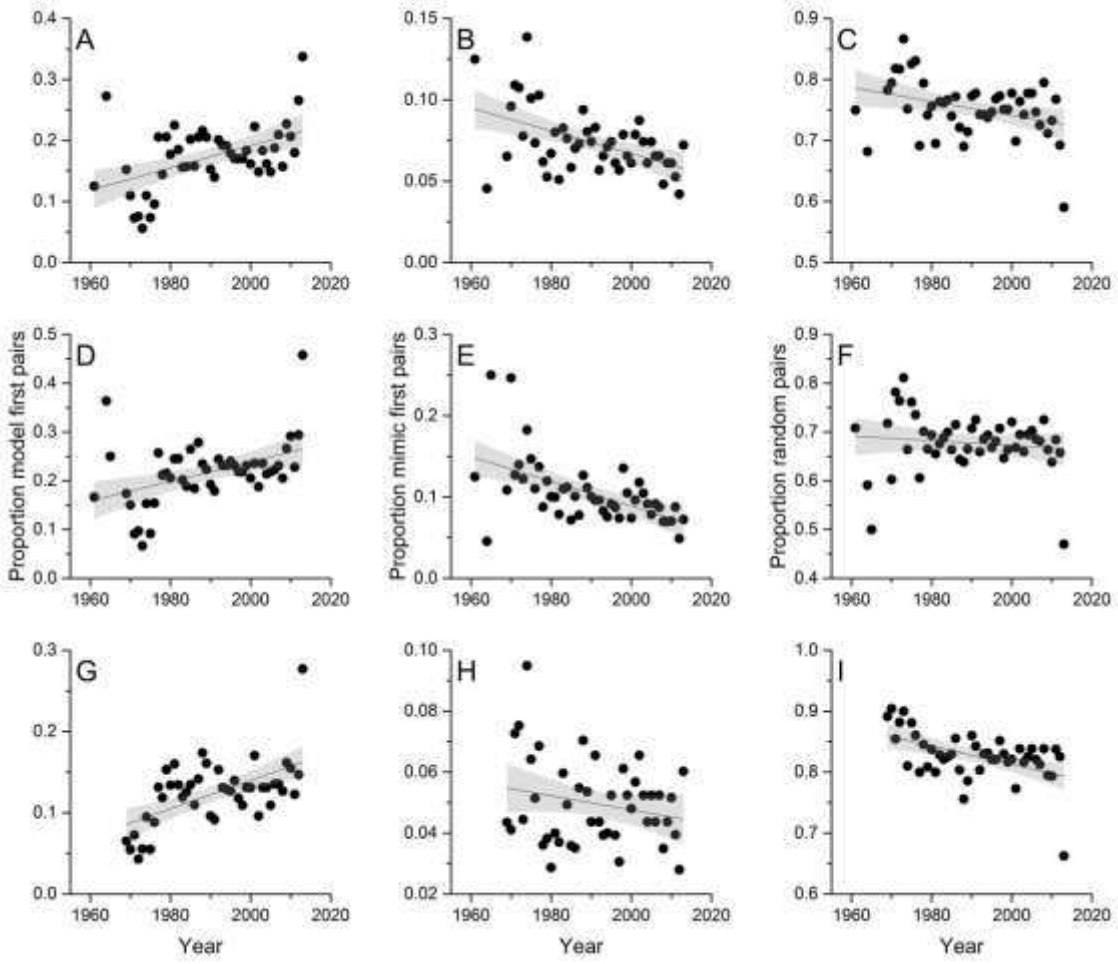

Fig. S10. Sensitivity analysis showing the proportion of 2,352 model-mimic pairs defined as each of three phenological scenarios (model-first, mimic-first, random) through time. The different panels show the effects of varying the threshold for clarification into each of the three categories: (A-C) mean 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.