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Disconnects between ecological theory and data in phenological mismatch research

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Supplementary Information

Literature search

We located papers relating phenological data from trophic interactions to fitness and/or performance of the consumer and/or the resource by conducting keyword searches in ISI Web of Science published up to June 2017. Keywords included phenolog* AND mismatch* OR synchron* AND interact* AND (fitness* OR performance*). Our initial search netted 2906 papers so we further refined our search by excluding categories that included engineering and computer science. This resulted in 393 papers. From these, we focused on observational studies and excluded studies if they did not: (1) measure phenology directly (e.g. used derived measures of phenology, such as NDVI or spring temperature); (2) measure phenology of at least one of the species; (3) quantitatively link consumer fitness or performance to the relative timing between consumer and resource; and (4) explicitly state that the two species interacted (e.g. specifying type of interaction). Estimates of consumer fitness or performance (i.e., growth or development) had to be direct estimates (e.g. we did not include studies that used diet proportions to measure consumer performance) and included a range of proxies, for example, growth, survival, abundance. To ensure a reasonable sample size and to include studies across different major biomes, we included interactions that were resolved to the family-level and below. To reduce redundancy within systems, we only kept studies that were unique across pairs-location-year combinations. If more than one measure of phenology was included, we chose the one used by the authors to calculate mismatch and examine its impact on performance.

Our final review included 42 studies with 45 pair-wise species interactions (3 studies had 2 interactions). These studies encompassed terrestrial, marine and freshwater ecosystems as well as a large latitudinal gradient.

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Summary of studies and interactions

Based on the type of data collected for the consumer and resource, we classified studies as life history (i.e. one that collected data at the individual level) or one that collected data at the population or community (i.e., across species). To determine whether studies had the potential to define pre-climate change baselines, we measured the study's time span and years of data based on the years where phenology data was available for both the consumer and resource, and consumer performance data was available.

The majority of the studies (26/42) focused on: i) documenting how climate change is affecting the timing of a trophic interaction and how those changes have affected the consumer's performance; and ii) evaluating the roles of abiotic and biotic factors in influencing synchrony. The ultimate goal of these studies was to predict the impacts of climate change on pair-wise species interactions. Our database also included studies (16/42) whose aim was to understand the underlying processes related to timing (e.g., coevolution, life history trade offs, food web dynamics) that drive consumer or resource dynamics, independently of climate change. Another divide across studies was whether performance of the consumer was measured at the individual level (27/45 interactions) or at the population or community level (18/45 interactions; see Table S1).

Additional details for Box 2

Raw data for panel (a) was obtained from Figure 3 in Tikkanen and Julkunen-Tiitto (2003). The data come from two related experiments where the authors manipulated the number of days that neonates (i.e. early instar larvae) spent without food (first experiment) and the emergence times of larvae relative to budburst (second experiment). In the first experiment, there were six groups of 30 larvae that spent 0, 5.5, 11, 22, 27.5 and 33 degree-days without food. In the second experiment, there were four cohorts, each separated by intervals of 3-5

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days. All *O. brumata* eggs and larvae originated from laboratory stock originally from Turku, Finland whereas the foliage originated from trees near Banchory, NW Scotland. Consequently, data for the figure are from different populations.

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Tables

Table S1. A comparison across studies of the type of performance data collected for consumer and resource. We define a life-history study as one that collected data at the individual level and a population/community study as one that collected data at the population or community (i.e., across species) level. Counts in the table are numbers of individual pair-wise interactions (n=45).

		Resource performance					<i>Totals</i>
		Life-history		Population/Community			
		None	Individual	Population	Community		
Consumer performance	Life-history	Individual	6	0	4	17	<i>27</i>
	Population/Community	Population	1	1	7	7	<i>16</i>
		Community	0	0	1	1	<i>2</i>
Total			7	1	12	26	45

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Table S2. A comparison across studies of the type of performance data collected for the consumer across systems and taxonomic group. Counts in the table are numbers of individual pair-wise interactions (n=45).

		System		Taxonomic group			
		Aquatic	Terrestrial	Invertebrate	Vertebrate		
					Fish	Bird	Mammal
Level of consumer performance	Individual	5	22	1	2	19	5
	Population	14	2	9	4	2	1
	Community	1	1	2	0	0	0
	Sub-totals	20	25	12	6	21	6
Totals		45		45			

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