Are peak emergence and emergence duration related directly to stream temperature in aquatic insects?

Spatiotemporal patterns of emergence phenology reveal complex species-specific responses to temperature in aquatic insects

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Can emergence duration and peak emergence date by predicted by calculating cumulative degree days or are there species-specific patterns that indicate more complex responses?

The phenology, or timing, of adult stage emergence for aquatic insects is related to water temperature. A warming thermal regime resulting from global change may induce insects to emerge earlier potentially creating a mismatch with resources. Warming may also cause an extended emergence period, which may adaptively increase adult activity periods in productive years. The researchers studied four common spring-emerging aquatic insects to determine whether 1) adults emerged earlier and 2) the emergence period was longer in warmer streams and years.

How did stream temperature vary among years and streams?

- Stream temperature varied among years and streams. Differences across streams generally followed the expected pattern based on elevation, forest age, and hydrology.

Did peak emergence vary among or the required cumulative degree-days vary among streams?

- Of the four focal species, mean ordinal date of emergence varied strongly among streams only for the caddisfly *Dolophilodes*, which had significantly earlier emergence in warmer streams.
- All four species required fewer degree-days to peak emergence in colder streams than in warmer streams.

Did emergence duration vary among streams?

- Emergence duration differed among streams for *Dolophilodes*, *Alloperla* (stonefly), and *Neoleptophlebia* (mayfly), with higher-elevation, colder streams having shorter emergence windows.

How was peak emergence related to stream temperature?

- In general, peak emergence timing was earlier when stream temperature was higher. For *Dolophilodes*, emergence was earlier in warmer years and in warmer streams within a year. *Alloperla* and *Neoleptophlebia* emerged earlier in warmer years but within a year emergence did not differ among streams.
- For *Moselia*, overall emergence was weakly earlier with warmer temperature, but there were no patterns within streams or years because of high scatter around the best fit lines. The authors posit that this pattern may be common for species with long emergence duration and variable peak emergence.

- The stonefly *Moselia* had the longest emergence duration, the earliest emergence, and the most variability in emergence duration and peak emergence date.

What kind of phenological responses did the emergence patterns suggest?

- The strong synchronicity of emergence across streams within years demonstrated by *Alloperla* and *Neoleptophlebia* suggests a period of dormancy. The current study provides evidence that such drivers might synchronize life cycle events across smaller spatial scales than previously recognized.
- Emergence duration was longer in warmer streams, suggesting a temperature cue for decreased synchronicity. Perhaps populations in warmer streams do not enter a dormant period, which would have acted to increase synchronicity.
- Alternatively, warmer winter conditions my trigger a different complex set of responses because longer emergence duration after warmer winter conditions may provide a selective advantage by allowing populations to take advantage of longer breeding seasons.

What additional research would increase our understanding of aquatic insects' phenological responses?

- More research is needed to understand how summer and winter thermal regimes may influence the timing and duration of aquatic insect life cycle events. The responses driving interannual differences are likely complex.
- Experimental studies that cover the entire life cycle could provide important information on the impact of thermal cues.
- Cooperative studies with physiologists could improve detection and understanding of phenological responses.

What can the results of this study tell us about potential responses to and impact of climate change on aquatic insects?

- In complex heterogenous basins with temperature differences within and among streams there may be enough variability to buffer species against changing climate conditions.
- The authors propose that there may be a tradeoff for species between strong phenological responses influencing emergence synchronicity and adult longevity and dispersal ability, such as flight strength.
- In aquatic insects, some traits have high plasticity and other traits may evolve quickly, which may increase phenological response flexibility and ecosystem-scale resilience.

Research Approach/Methods

- The authors focused on the four most abundant aquatic insects with spring emergence across six headwater streams in the Cascade Range, Oregon from 2006 to 2014.
- The researchers calculated degree days, accumulated temperature units over time, in each stream reach using data logged every half hour, converted to an hourly time-step, and averaged for a daily temperature.
- They deployed four emergence traps per stream reach during spring and early-summer to collect and preserve emergent insects, for later identification.

- The authors calculated the degree days over the first 189 days of the year as a measure of the warmth of each stream. They also calculated the degree days from mid-winter until peak emergence for each species in each stream.
- The researchers used ANOVA to determine whether emergence timing, emergence duration, or degree day accumulation through peak emergence varied among streams for each species.
- They used ANCOVAs to determine whether there was a consistent negative relationship between peak emergence timing and temperature by stream and separately by year.

Keywords aquatic insects, headwater streams, life history traits, phenology, temperature

Images

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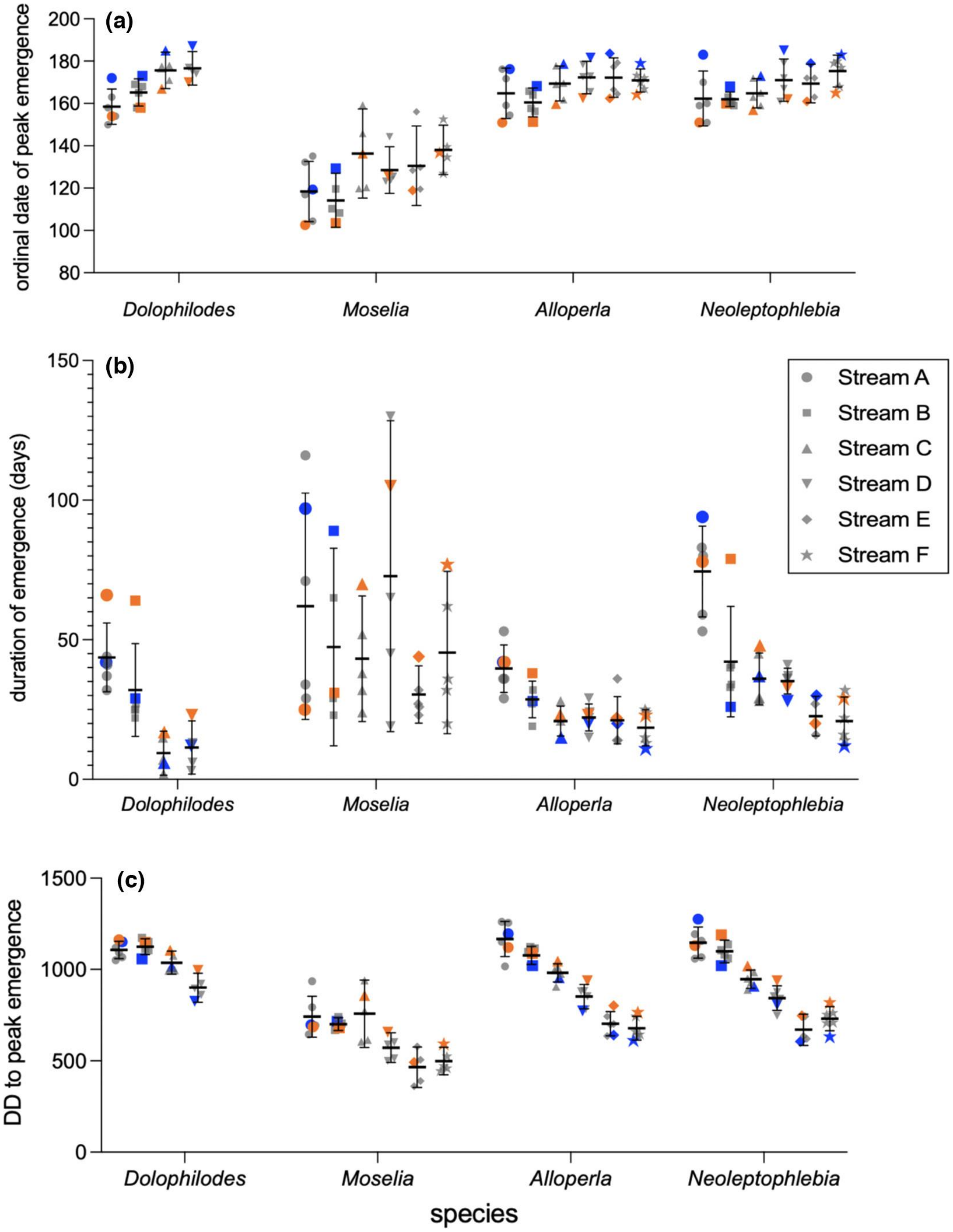

Figure 4 from Finn et al. 2022. (a) Timing of peak emergence varied among species but did not vary strongly among streams. For each of the four species, peak emergence timing is grouped by stream, and points within streams represent different years. (b) Duration of emergence periods calculated as number of days between 5th and 95th percentiles of Gaussian models for each stream/year and for each of the four species. For each species, emergence durations are grouped by study stream, and points within streams represent different years. (c) Degree-days (DD) accumulated to peak emergence date varied spatially, with higher-elevation streams on average requiring significantly fewer DD, especially in the “Pattern 3” species (*Alloperla* and *Neoleptophlebia*). In each panel, horizontal lines for each species/stream are means; error bars are 95% confidence intervals. Points marked in orange are from the warmest sample year (2014); points in blue are from the coolest sample year (2011). Points only plotted for species/stream/year with fitted normal distributions. *Moselia* was missing 2011 data for streams C–F because modelled peak emergence occurred later than the empirical collection period in the coolest year, and those data were discarded.

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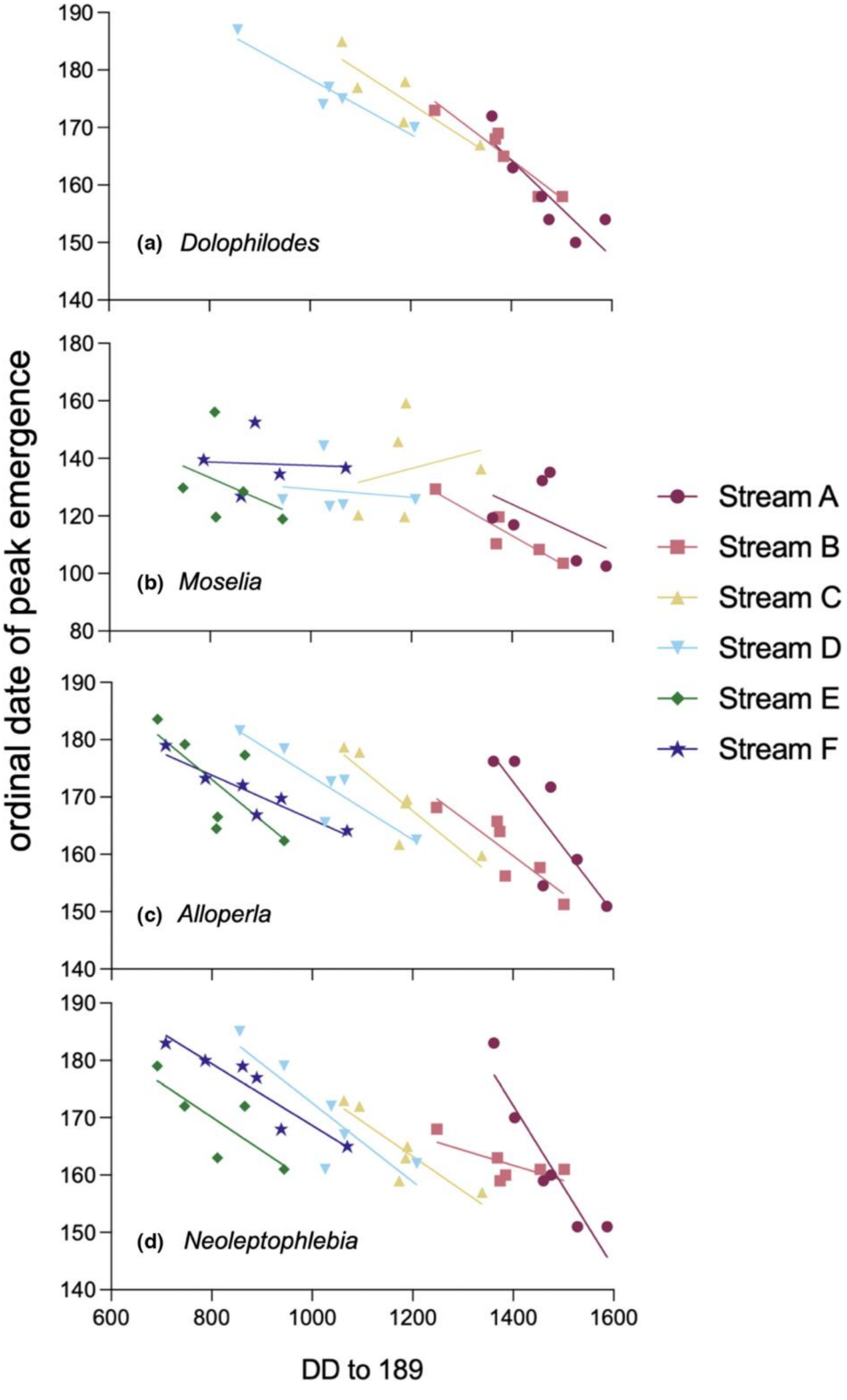

Figure 5 from Finn et al. 2022. Plots of ordinal date of peak emergence versus temperature as cumulative degree-days (DD) through mid-year (ordinal date 189) for all stream/year combinations for which Gaussian models could be fit. (a) *Dolophilodes dorca*; (b) *Moselia infuscata*; (c) *Alloperla fraterna*; (d) *Neoleptophlebia temporalis*. Note difference in Y-axis scale for earlier-emerging *Moselia*. Lines are best-fit linear regressions for each stream. See Tables 3 and 5 for statistical results.

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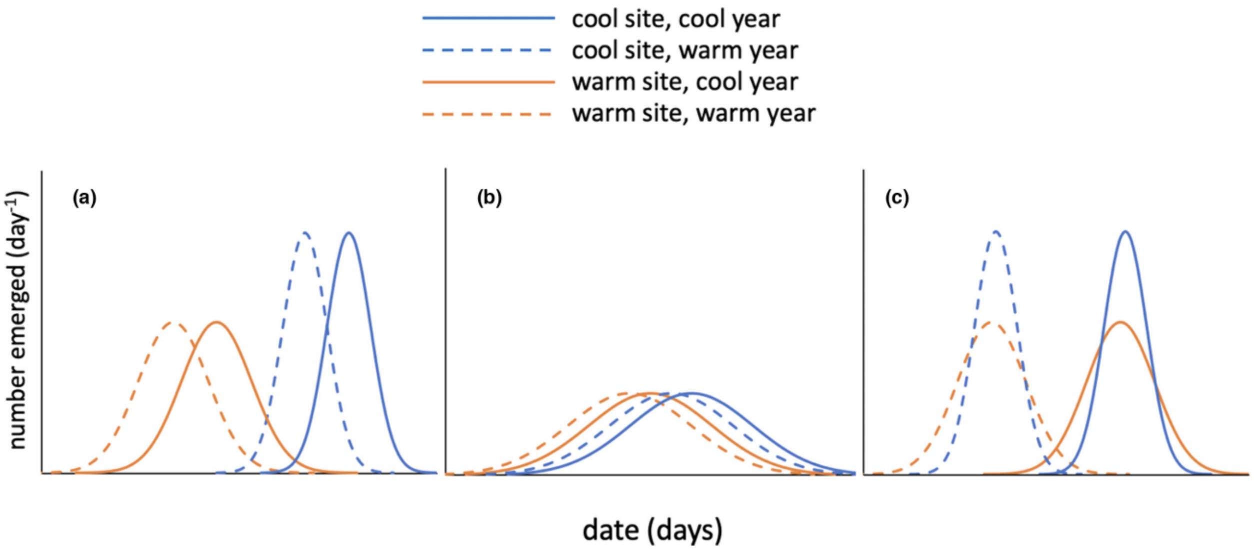

Figure 6 from Finn et al. 2022. Conceptual diagrams representing three major patterns of emergence timing and duration observed in this study. (a) Pattern 1: relatively consistent spatial and temporal response of emergence timing to temperature, and longer duration of emergence period in warmer years and at warmer streams (*Dolophilodes*); (b) Pattern 2: some evidence for response to heat accumulation rate but overall lengthy emergence periods make patterns difficult to distinguish among streams and years (*Moselia*); (c) Pattern 3: temporal (among-year) response to temperature but spatial near-synchrony of emergence timing across cooler and warmer streams within years, with longer emergence period in warmer years (*Alloperla* and *Neoleptophlebia*).

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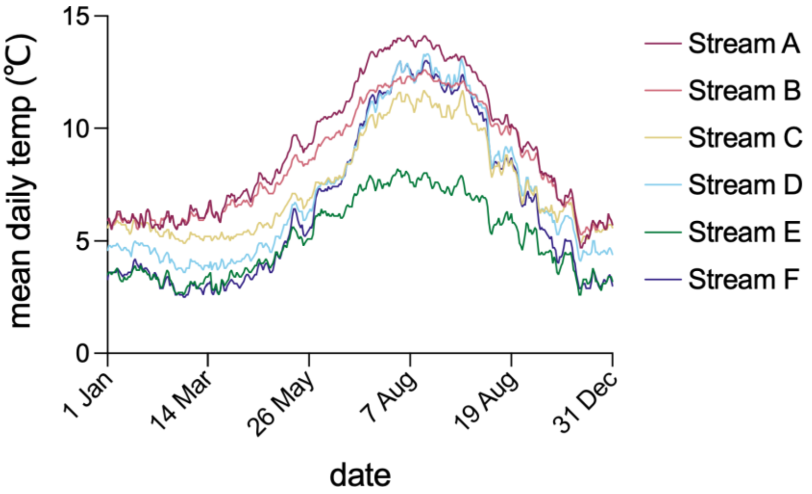

Figure 3 from Finn et al. 2022. Mean daily water temperature for each of the six streams across the 6 years of the study period. Note: mean daily values for dates 1 Aug to 31 Dec are based on 5 years of data (2009–2013) because the study ended after July 2014 (the 6th year of study).