



Thermal ecology and sexual selection in ectotherms

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Abstract. Temperature is a fundamental ecological factor that shapes the expression of reproductive traits and the dynamics of sexual selection in ectothermic animals. This mini-review synthesizes current evidence on how thermal conditions influence sexually selected signals, mate preferences, reproductive behaviour, mating dynamics, gamete performance, and sex-specific reproductive responses across diverse ectotherm taxa. Available evidence indicates that temperature can modify visual, vibratory, acoustic, and colour-based sexual signals, while simultaneously altering female preferences and the degree of signal-preference coupling. Thermal variation may therefore either maintain or disrupt the correspondence between male signals and female choice, with important consequences for mating success. Temperature also constrains reproductive activity by modifying activity windows, thermoregulatory behaviour, courtship opportunities, and the allocation of energy to reproduction. Beyond pre-copulatory processes, thermal conditions affect sperm quantity and quality, sperm competition, fecundity, fertility, and post-copulatory sexual selection. Importantly, males and females may differ in their thermal sensitivity, producing sex-specific effects on reproductive success and potentially modifying the strength and direction of sexual selection. The evidence further suggests that thermal plasticity is often insufficient to compensate for rapidly changing thermal environments. Consequently, warming may generate mismatches between sexual signals, mate preferences, reproductive physiology, and environmental conditions, with implications for population viability and evolutionary adaptation. Understanding the reciprocal interactions between thermal ecology and sexual selection is therefore essential for predicting how ectothermic organisms will respond evolutionarily to ongoing climate change.

Keywords: temperature, sexual signals, mate choice, signal-preference coupling, reproductive behaviour, sperm competition, gamete performance, thermal plasticity, climate change, evolutionary adaptation.

Introduction. Temperature modulates sexual selection in ectotherms through both direct effects on secondary sexual traits and preferences and indirect effects on mating parameters, demography, and reproductive trade-offs (García-Roa et al., 2020). A meta-analysis across experimentally manipulated temperature studies confirmed a clear association between temperature and sexual selection measures in both sexes (García-Roa et al., 2020). Despite this, the specific role of temperature as a modulator of sexual selection has been largely neglected relative to other ecological factors (García-Roa et al., 2020). Most sexual selection research has been conducted under constant laboratory temperatures that do not reflect the fluctuating thermal environments in which selection naturally unfolds (García-Roa et al., 2020; Petrescu-Mag, 2025). Reciprocal evolutionary feedbacks between thermal ecology and sexual selection may be necessary to understand how organisms adapt to past and future environments (Leith et al., 2022).

Aim of the Review. The aim of this mini-review is to synthesize current evidence on the role of temperature as a modulator of sexual selection in ectothermic animals. Specifically, the review examines how thermal conditions influence sexually selected signals and female mate preferences, reproductive behaviour and mating opportunities, pre- and post-copulatory processes, gamete performance, and sex-specific reproductive responses. Particular attention is given to the potential disruption of signal-preference coupling under thermal stress and to the consequences of thermal variation for the strength and direction of sexual selection. By integrating behavioural, reproductive, physiological, and evolutionary perspectives, this review seeks to clarify how thermal ecology and sexual selection interact and how these interactions may influence the capacity of ectothermic populations to persist and adapt under ongoing climate warming.

Temperature Effects on Sexual Signals. Temperature directly alters the expression of sexually selected signals across multiple sensory modalities. In the jumping spider *Habronattus clypeatus*, male visual and vibratory courtship behaviors became faster, higher-pitched, and lower in amplitude at higher temperatures, with a curvilinear relationship asymptoting around 40°C (Brandt et al., 2018). In the wolf spider *Schizocosa floridana*, different components of a complex multicomponent song responded differently to daily thermal variation, with some increasing in production rate, others decreasing, and some unaffected (Rosenthal & Elias, 2019). Selection on courtship shifted with temperature in complex ways, with some display components experiencing directional selection at higher but not lower temperatures (Rosenthal & Elias, 2019). In a follow-up study on *H. clypeatus*, temperature impacted only vibratory courtship and not visual sidling courtship, yet females expressed preference for sidling courtship only at the higher temperature (Brandt et al., 2020). These findings underscore that temperature can alter which signal components are under selection without uniformly degrading all signal modalities.

Acoustic sexual signals are similarly temperature-dependent. Calling behaviour in anuran amphibians is strongly temperature-dependent and critical for sexual selection, with all studied species showing wide thermal breadths during calling above 15°C (Llusia et al., 2013). Calling temperatures differed both geographically and seasonally and were 8–22°C below species-specific upper critical thermal limits, suggesting population-specific thermal ranges that may involve plasticity of seasonal and developmental acclimation mechanisms (Llusia et al., 2013). Global warming would not directly inhibit calling in the studied species, though it might affect other temperature-dependent features of their acoustic communication system (Llusia et al., 2013) (Table 1).

Table 1

Temperature effects on sexual signals across ectotherm taxa, spanning visual, vibratory, acoustic, and colour modalities

Signal type	Species	Temperature effect	Selection consequence
Multimodal (visual + vibratory)	<i>Habronattus clypeatus</i>	Signals faster, higher-pitched, lower amplitude; asymptote ~40°C	Mating rates highest above field peak activity temperatures (Brandt et al., 2018)
Multicomponent vibratory song	<i>Schizocosa floridana</i>	Components differ in thermal sensitivity	Directional selection on some components only at high temperatures (Rosenthal & Elias, 2019)
Acoustic (calling)	Five temperate anurans	Calling temperatures shift geographically and seasonally	Population-specific thermal ranges; acclimation may buffer climate change (Llusia et al., 2013)
Colour ornamentation	<i>Tropidurus spinulosus</i>	Ventral darkening at preferred temperature but not at high temperature	Climate change may impair plastic colour adjustment (Rossi et al., 2024)

Signal type	Species	Temperature effect	Selection consequence
Orange colouration	<i>Poecilia reticulata</i>	Decreased after experimental heatwave	Compromised ornament central to female choice (Breedveld et al., 2023).

Colour ornaments, a classic target of female mate choice (Popescu & Păpuc, 2025; Petrescu-Mag et al., 2025; Petrescu-Mag, 2009), are also thermally sensitive. In the guppy *Poecilia reticulata*, experimental heatwave exposure (32°C for five days) caused a decrease in orange colouration, the most important ornament on which female choice is based (Breedveld et al., 2023). In the lizard *Tropidurus spinulosus*, males enhanced dichromatic coloration during the reproductive season, and at their preferred temperature could darken ventral coloration, but no such plastic change was observed at high temperatures simulating climate change scenarios (Rossi et al., 2024). Increasing temperatures thus appear to impair the capacity of males to adjust their coloration plastically during the reproductive season (Rossi et al., 2024).

Signal-Preference Coupling and Mate Choice. A central concern is whether temperature drives male signals and female preferences in the same direction, preserving signal - preference coupling, or in discordant directions, producing de-coupling that disrupts sexual selection. In treehoppers, developmental temperature affected the thermal sensitivity of courtship behavior and mating signals for males but did not affect the thermal sensitivity of courtship or mate preferences in females (Macchiano et al., 2023). This sex-specific plasticity did not alter the likelihood of mating across ambient temperatures but did disrupt how closely mating signals and preferences matched each other at higher ambient temperatures (Macchiano et al., 2023). The resulting partial signal-preference de-coupling predicts that the thermal sensitivity of sexual selection will depend on developmental conditions (Macchiano et al., 2023). If males and females respond to environmental shifts in discordant fashions, developmental plasticity alone could disrupt mating dynamics and population viability on a broad scale (Macchiano et al., 2023).

Temperature also affects mate choice through behavioural mechanisms rather than signal perception alone. In *T. spinulosus*, the time allocated to mate choice generally decreased with increasing temperature because individuals increased use of thermal refuges, supporting the hypothesis of "missed opportunities" (Rossi et al., 2023). At high temperatures, both sexes showed changes in mate selection dynamics, with females possibly rushing mate choice and males showing increased intermale variability of reproductive displays (Rossi et al., 2023). In *H. clypeatus*, females were more likely to allow males to progress to later stages of courtship and had higher mating rates at higher temperatures, yet laboratory mating rates peaked at temperatures potentially above those during peak field activity (Brandt et al., 2018). Females also preferred to mate with heavier males at all temperatures and preferred males performing shorter sidling displays (Brandt et al., 2020). Temperature can further disrupt mate choice by interfering with pheromonal communication, impairing the female's ability to assess and choose an appropriate partner (Breedveld et al., 2023).

Reproductive Behaviour and Mating Dynamics. Temperature constrains the opportunity for reproductive behaviour by restricting activity windows. In a temperate lizard, populations exposed to cool thermal regimes presented fewer high-activity days, and although plasticity in male thermal activity responses masked overall differences in activity levels, prolonged restriction affected the timing and consistency of male-female interactions (Moss et al., 2023). Females were less capable than males of compensating for lost activity time under cold stress, and less active females were significantly less likely to reproduce (Moss et al., 2023). Sex-biased activity suppression limited male mating rates but did not correspond to a heightened intensity of sexual selection or shifts in its targets (Moss et al., 2023). In many populations facing thermal activity restriction,

sexual selection on males may play a limited role relative to other thermal performance traits in facilitating adaptation (Moss et al., 2023).

At the other thermal extreme, high temperatures force ectotherms to allocate more time to thermoregulation and shelter-seeking, reducing opportunities for social and reproductive interactions (Rossi et al., 2023). High environmental temperatures in *T. spinulosus* were associated with a bimodal pattern in daily activity linked to thermal quality of the habitat, whereas the pattern and frequency of social displays showed less plasticity (Rossi et al., 2023). Low plasticity in upper critical temperatures suggests a limitation of ectotherms to adapt to warming environments (Rossi et al., 2023). Thermal stress can also divert energy from sexual behaviour to repair or maintenance processes, decreasing sexual activity or shifting mating tactics, which can in turn increase the intensity of sexual conflict (Breedveld et al., 2023). In guppies, heatwave exposure shifted the preferred male mating tactic towards forced copulation attempts, which override female mate choice and carry implications for sexual conflict dynamics (Breedveld et al., 2023) (Table 2).

Table 2

Sex-specific pre- and post-copulatory reproductive responses to thermal conditions across five ectotherm species

<i>Species</i>	<i>Thermal condition</i>	<i>Pre-copulatory effect</i>	<i>Post-copulatory effect</i>
<i>Poecilia reticulata</i>	Heatwave (32°C, 5 days)	Decreased sexual activity; shift to forced copulation; reduced orange ornament	More sperm but lower quality; increased variance in sperm number (Breedveld et al., 2023)
<i>Lasioderma serricorne</i>	19, 25, 31°C	No effect on mating rate, latency, or courtship intensity	Sperm transfer and fecundity peaked at 25°C; extreme temperatures promoted polyandry (Suzaki et al., 2018)
<i>Lacerta agilis</i>	Decadal warming	Increased mating rate and sires per clutch	Multiple paternity reduced malformed offspring; OSR constrained sexual selection on body size (Olsson et al., 2011)
<i>Tribolium castaneum</i>	Heat stress	Polygamy magnified detrimental heat effects on male reproductive success	Polygamy relaxed negative effects in females (Moiron et al., 2022)
<i>Pieris napi</i>	29°C development	Mating success reduced in heat-stressed females	Near-complete male sterility via disrupted eupyrene and apyrene sperm (Smith et al., 2025).

A decade-long field study of sand lizards (*Lacerta agilis*) revealed that elevated temperature increased mating rate and the number of sires per clutch, with positive effects on offspring fitness (Olsson et al., 2011). Increased number of sires contributing to within-clutch paternity decreased the risk of malformed offspring (Olsson et al., 2011). However, the strength of sexual selection on body size could not be explained by variation in mean temperature during the mating season but was significantly constrained by the population operational sex ratio (Olsson et al., 2011). In years when partner quality was more variable, clutches showed less multiple paternity, consistent with laboratory trials showing stronger cryptic female choice when male quality varied more (Olsson et al., 2011). These results suggest that the thermal environment acts as a constraint on mating systems regardless of physiological phenotypic plasticity (Olsson et al., 2011).

Post-Copulatory Processes and Gamete Performance. Temperature effects extend beyond pre-copulatory behaviour to post-copulatory sexual selection, where gamete traits and sperm competition are thermally sensitive. In the cigarette beetle *Lasioderma serricorne*, thermal conditions did not affect precopulatory traits but mating duration increased with decreasing temperature, and the number of sperm transferred and female fecundity were greatest at an intermediate 25°C (Suzaki et al., 2018). When females first mated at extreme temperatures, polyandry was promoted, potentially favouring males with higher sperm competitive ability through increased likelihood and intensity of sperm competition (Suzaki et al., 2018). The paternity of the first male was highest at the intermediate temperature, and paternity shifts could be attributed to decreased sperm transfer at thermal extremes (Suzaki et al., 2018). Thermal conditions thus affect the relative weight of pre- versus post-copulatory episodes of sexual selection, which determines the total opportunity for selection (García-Roa et al., 2020).

In guppies, heatwave-exposed males had more sperm but of lower quality, with increased variance in sperm number, suggesting a compromised ability to secure fertilizations (Breedveld et al., 2023). Changes in sperm quality are likely to impair sperm competitiveness and thus the outcome of sperm competition and the opportunity for sexual selection at the post-mating level (Breedveld et al., 2023). In the butterfly *Pieris napi*, heat-stressed males exhibited near-complete sterility mediated by disruption to both fertilising eupyrene and non-fertilising apyrene sperm production or transfer, and male remating did not recover fertility (Smith et al., 2025). The temperature threshold at which fertility deteriorates is often below an organism's lethal thermal limit, meaning populations may face decline driven by sub-optimal fertility of otherwise viable individuals before lethal effects manifest (Breedveld et al., 2023). In female guppies, the heatwave significantly affected survival and impaired fecundity, with many females from the heatwave treatment not reproducing at all (Breedveld et al., 2023).

Sex-Specific Thermal Sensitivity and Evolutionary Implications. Males and females differ in their thermal sensitivity of reproductive traits, and these sex-specific responses have consequences for sexual selection dynamics and population adaptation. In *P. napi*, mating success was reduced in heat-stressed females but not in males, while egg production and fertility were unaffected in females but heat-stressed males exhibited near-complete sterility despite longer copulation durations (Smith et al., 2025). In *T. castaneum*, polygamy magnified detrimental effects of heat stress on male reproductive success but relaxed negative effects in females, suggesting sexual selection can reverse sex differences in thermal sensitivity and alter sex-specific selection on alleles associated with heat tolerance (Moiron et al., 2022). Sexual selection intensifies net selection on heat resistance in males but not in females, and assuming alignment of natural and sexual selection, this may promote adaptation to current global warming (Moiron et al., 2022).

A meta-analysis of sex differences in thermal acclimation capacity across ectotherms revealed that males and females did not differ significantly in their overall capacity to acclimate their thermal limits and preference (Pottier et al., 2021). However, in some instances females expressed significantly greater plastic responses than males, including greater heat tolerance plasticity in wild animals and greater cold tolerance plasticity in terrestrial habitats (Pottier et al., 2021). The capacity for each sex to adjust thermal tolerance and preference was remarkably limited and likely insufficient to compensate for the impacts of climate change (Pottier et al., 2021) (Figure 1).

Thermal Ecology and Sexual Selection in Ectotherms

Temperature shapes sexual signals, preferences and mating outcomes

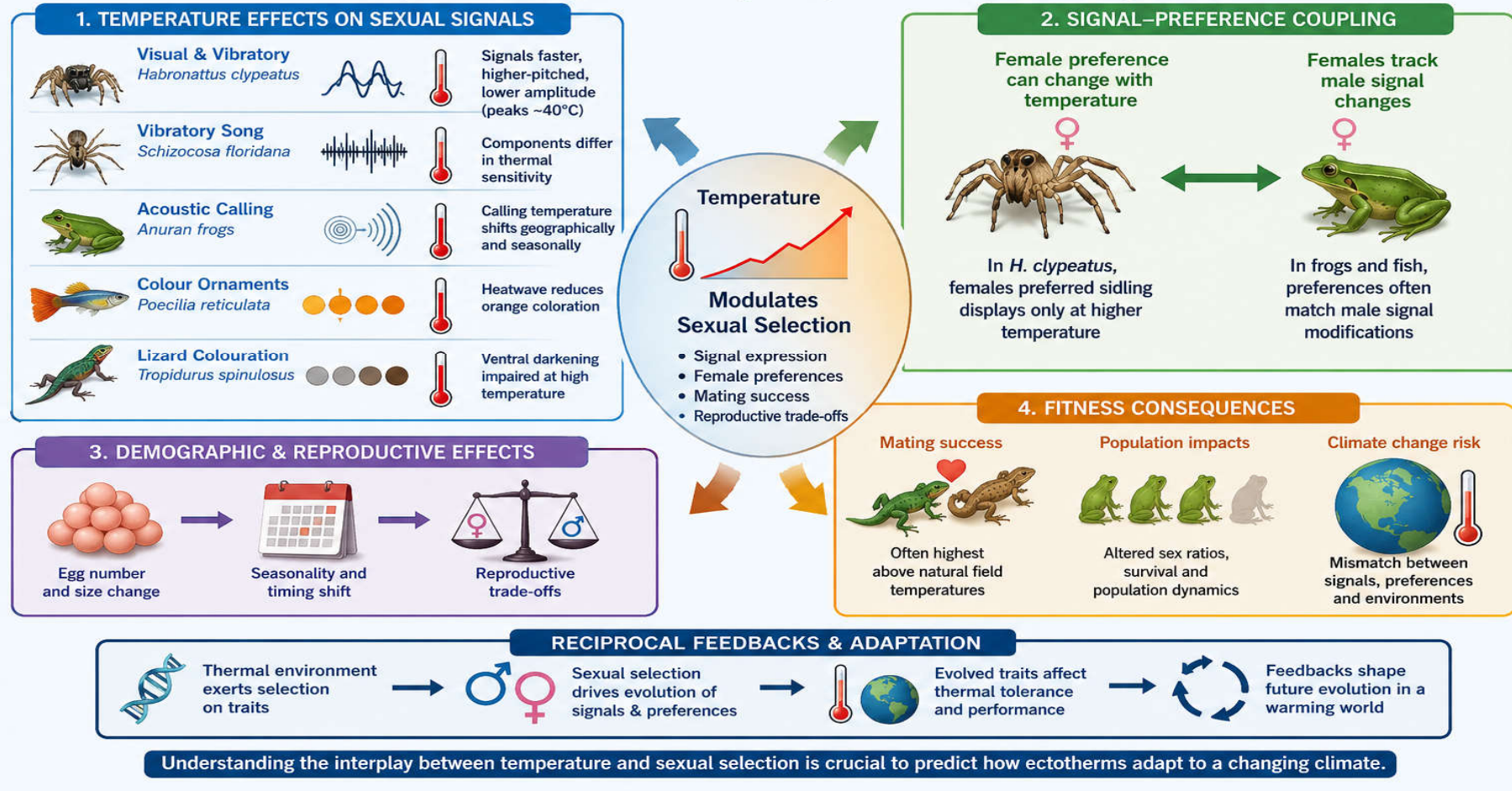


Figure 1. Thermal ecology and sexual selection in ectotherms.

Over 75% of identified studies either did not report or confounded the sex of the animals, which may cause researchers to overlook ecologically relevant sex differences in plasticity (Pottier et al., 2021)

In spiders, sex-specific spatial ecology creates differential heat exposure: adult females in many species are sedentary web-builders limited in their ability to move to cooler microhabitats, while nomadic males may be better able to escape heat by seeking refuge (Harvey & Dong, 2023). Selection to extreme temperatures may drive adaptive responses in female physiology, morphology, or web site selection in species building small or exposed webs (Harvey & Dong, 2023). In two congeneric damselfly species, natural selection favoured reduced thermal reaction norm slopes at high ambient temperatures, suggesting current thermal plasticity is maladaptive in the context of anthropogenic climate change and that selection promotes thermal canalization and robustness (Svensson et al., 2020). Thermally mediated selection on one sex could positively influence fitness for the other, as sexually concordant selection could facilitate climatic adaptation in both males and females (Svensson et al., 2020). Although studied in an endotherm, zebra finch males exposed to acute thermal challenge showed differential expression of hundreds of genes in the testes but few in the brain, with gene network analyses revealing that dopaminergic signalling in the brain covaried with heat dissipation behaviours, providing a mechanism by which thermal challenges may alter motivational circuits for song production (Lipshutz et al., 2022). These gene regulatory changes suggest individual variation in thermal response could impact sexually selected traits in a warming world (Lipshutz et al., 2022).

Conclusions. Temperature should be regarded not merely as a physiological constraint but as an important ecological and evolutionary modulator of sexual selection in ectotherms. Thermal variation can modify the production and expression of sexually selected signals across multiple sensory modalities, alter female mate preferences, and change the correspondence between sexual signals and preferences. These effects can influence mating success and the opportunity for sexual selection even when temperature does not directly reduce overall mating rates.

Thermal conditions also affect reproductive dynamics beyond mate choice. Changes in activity periods, thermoregulatory behaviour, courtship opportunities, fecundity, sperm quantity and quality, sperm competition, and fertility demonstrate that temperature can influence both pre-copulatory and post-copulatory components of sexual selection. Importantly, thermal sensitivity may differ between males and females, potentially generating sex-specific selection pressures and altering the evolutionary consequences of warming.

A recurrent concern is that the capacity for thermal plasticity and acclimation may be insufficient to compensate for rapidly increasing environmental temperatures. Consequently, reproductive impairment may occur at temperatures below lethal thermal limits, making sexual and reproductive traits particularly relevant indicators of climate vulnerability. Disruption of signal–preference coupling, reduced reproductive opportunities, impaired gamete performance, and sex-specific thermal responses may collectively influence population dynamics and evolutionary trajectories.

Overall, the available evidence supports a reciprocal relationship between thermal ecology and sexual selection: temperature modifies the expression and outcome of sexual selection, while sexual selection may subsequently shape the evolution of traits associated with thermal tolerance and reproductive performance. Incorporating this interaction into studies of climate change is therefore essential for understanding the adaptive potential and persistence of ectothermic populations in increasingly variable and warmer environments.

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