



HAL
open science

Hormonal regulation of parental care in insects: a call for exploring vulnerabilities to anthropogenic pollutants

Charlotte Lécureuil, Laura Pasquier, Joël Meunier

► To cite this version:

Charlotte Lécureuil, Laura Pasquier, Joël Meunier. Hormonal regulation of parental care in insects: a call for exploring vulnerabilities to anthropogenic pollutants. *Current Opinion in Insect Science*, 2025, 73, pp.101451. <10.1016/j.cois.2025.101451>. <hal-05338016>

HAL Id: hal-05338016

<https://univ-tours.hal.science/hal-05338016v1>

Submitted on 30 Oct 2025

HAL is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.



HAL Authorization

Hormonal regulation of parental care in insects: a call for exploring vulnerabilities to anthropogenic pollutants

Charlotte Lécureuil, Laura Pasquier, Joël Meunier

Institut de Recherche sur la Biologie de l'Insecte, UMR 7261, CNRS, University of Tours, Tours, France

Corresponding author: C Lécureuil

ORCID

C Lécureuil ##0000-0002-7339-9185

L Pasquier ##0009-0000-1346-2069

J Meunier #0000-0001-6893-2064

HIGHLIGHTS

- Studying EDCs in insects is urgent to predict pollution effects on population declines
- EDC research is taxonomically biased, with most studies focused on vertebrates
- Hormonal regulation of insect parental care is poorly understood
- Studies of EDC effects on insect parental care are sparse and mostly correlative
- We propose five research priorities to fill these critical knowledge gaps

ABSTRACT

Global insect populations are declining at an alarming rate, threatening biodiversity and the ecosystem services on which humans depend. One potential driver of this decline is the alteration of key biological functions, including parental care, by anthropogenic factors such as chemical pollution and exposure to endocrine-disrupting compounds (EDCs). This review synthesizes current knowledge on how EDCs may affect insect parental care, highlighting major gaps and opportunities for research. We first discuss the taxonomic bias in EDC research and its implications for understanding insect susceptibility. We then summarize what is known about the hormonal regulation of insect parental care, emphasizing that current knowledge is limited to a few species, a few behaviours, and primarily juvenile hormone. Next, we examine the sparse evidence for direct or indirect effects of chemical pollutants on parental behaviors. Finally, we propose five research priorities to elucidate the interplay between EDC exposure, hormonal regulation, and parental care in insects: clarifying hormonal mechanisms, applying unbiased -omics approaches combined with functional analyses, identifying EDCs most likely to disrupt care, expanding taxonomic and behavioral coverage, and linking individual-level effects to population outcomes. Addressing these priorities is timely to establish causal links between hormones, behaviour, and pollutants, providing essential insights to predict and mitigate the impacts of EDCs on insect populations, ecosystem functioning, and evolutionary dynamics.

INTRODUCTION

Insect populations are declining globally, with reductions in abundance, biomass, and richness driving many species towards extinction [1–3]. Mounting evidence points to human activities - including light pollution, climate change, habitat destruction, and chemical pollution - as key drivers of this biodiversity crisis [2]. Among these, chemical pollutants are particularly concerning because they often persist in the environment, accumulate across trophic levels, and thereby expose insect populations to both immediate and long-term risks [4,5]. Understanding how pollutants affect insects is therefore critical, not only for preserving insect diversity but also for safeguarding the essential ecosystem services they provide.

Within this context, increasing attention is being directed towards pollutants that interfere with the endocrine system. Endocrine-disrupting compounds (EDCs) are defined by the WHO/IPCS as exogenous substances or mixtures that alter the function(s) of the endocrine system and can thereby induce adverse effects in individuals or populations [6]. To date, most research on EDCs has focused on vertebrates, reflecting the comparatively well-characterized nature of their endocrine physiology [7]. Consequently, both the definition and identification of EDCs have been shaped primarily by mammalian models [8]. Yet, this framework is incomplete: although insect and vertebrate endocrine systems share conserved features, including orthologues of several hormones [9–11], they also exhibit substantial divergences, which raises the risk of overlooking substances that specifically target insect hormones [12].

This neglect has far-reaching implications. Chemicals with little or no direct effect on mammalian endocrine systems may still perturb with insect hormonal pathways, with important ecological, agricultural, public health, and economic consequences. A striking example is provided by insect growth regulators (IGR), a class of pesticides designed to disrupt

insect endocrine signaling and control pest populations [13,14]. Although considered safe for vertebrates, IGRs should qualify as EDCs because they can also disrupt the endocrine systems of non-target insects [13,15]. Overall, the traditional mammalian-centered classification of EDCs has created an artificial divide between public health and biodiversity perspectives on chemical pollution. Bridging this divide is urgent and will require a comprehensive assessment of how EDCs affect insect endocrine systems, key physiological processes, and behaviour. Because these compounds persist, accumulate, and spread through shared resources such as water or soil, even local exposures can affect many individuals across species, ultimately scaling up to alter population dynamics, ecosystem functioning, and the services on which human societies depend.

Decades of research on vertebrates have shown that EDCs affect not only survival, development, and reproduction, but also a wide range of other biological processes critical to individual fitness, including behavior [16–22]. Among these behaviors, parental care is particularly noteworthy [23]. Defined as "any parental trait that enhances the fitness of a parent's offspring and is likely to have originated and/or is currently maintained for this function" [24], parental care is fundamental to juvenile survival in most vertebrates [25,26], and plays a similarly crucial role in many insects. About 5% of insect species (i.e., around 50,000 species) exhibit parental care [27], which can be performed by mothers, fathers, or both, and can last from brief moments to several years [28–31].

Insects perform a diverse array of parental behaviours that mitigate biotic and abiotic risks to offspring. These include pre-oviposition behaviours, such as oviposition site selection, and post-oviposition behaviours, such as nest maintenance, egg cleaning, incubation, predator deterrence, juvenile grooming, food provisioning, and the transfer of immune protection to offspring [27,32]. Even subtle disruptions of parental care can therefore have profound short- and long-term consequences for insect populations and diversity [33,34]. Experimental studies confirm that reduced or absent care drastically lowers offspring survival and reproductive success in insects such as burying beetles and earwigs [35,36], while long-term studies in vertebrates show that variation in parental investment can scale up to affect population growth, persistence and resilience under environmental change [37,38]. Despite this critical role, the effects of EDCs on insect parental care remain surprisingly understudied, representing not only a key frontier for basic research but also an urgent priority for understanding how chemical pollutants threaten insect biodiversity, agricultural productivity, and ecosystem stability [39].

HORMONAL REGULATION OF PARENTAL CARE

The effects of EDCs on insect parental care may remain understudied because, overall, endocrine regulation is far less understood in insects than in vertebrates. [26]. In vertebrates, parental behaviors are modulated by a complex network of hormones, including prolactin, oxytocin, and corticosteroids, whose natural or experimentally induced variations influence caregiving across numerous species [39]. Exposure to EDCs can disrupt these hormonal pathways, leading to maladaptive parental behaviors, with potentially severe consequences for offspring survival and population dynamics [39]. For instance, methylmercury has been linked to altered incubation behaviour in tree swallows (*Tachycineta bicolor*) [19], while developmental exposure in zebra finches (*Taeniopygia guttata*) reduced reproductive success across generations, with exposed pairs producing up to 50% fewer independent juveniles [40].

In mammals, EDCs can disrupt parental care by acting at least at two critical time points: during development, by affecting the establishment of parental neural circuits, and during adulthood, by directly altering the expression of parental behaviours. During pregnancy and lactation, a precisely timed hormonal sequence involving progesterone, estradiol, prolactin, and oxytocin orchestrates the maturation and activation of brain regions essential for maternal care, including the medial preoptic area and the reward circuitry [39]. Exposure to EDCs can alter this developmental process, leading to long-term deficits in maternal responsiveness. Additionally, EDCs can directly affect maternal behaviour in adulthood by perturbing the hormonal signals that regulate its expression, as demonstrated in rodent studies [39,41,42]. For instance, chronic mercury exposure in mice has been linked to reduced nursing and grooming behaviours, accompanied by alterations in hypothalamic gene expression affecting reproductive pathways and neural circuit regulation [41]. Likewise, perinatal exposure to an EDC mixture in rats led to multigenerational impairments in maternal care through hypothalamic epigenetic reprogramming, with dopamine-related gene deficits that were partially rescued through cross-fostering [42]. Overall, evidence from vertebrates demonstrates that EDC-induced disruption of hormonal pathways can impair parental care at multiple stages of life, ultimately threatening reproductive success and population stability across generations.

In insects, the hormonal regulation of parental care is comparatively less studied, and even less so in the context of potential disruption by chemicals such as EDCs (Figure 1). Most available data have focused on juvenile hormone (JH). This hormone is secreted by the *corpora allata*, a small endocrine gland located behind the brain, from which it regulates larval growth, molting, pupation, and reproductive functions such as oogenesis [43–45]. To our knowledge, no study has reported a lack of association between JH and parental care; rather, existing studies reveal two contrasting patterns, with some suggesting that JH inhibits care, and others proposing that it promotes care (Figure 1 for details). Beyond JH, other hormones and hormone-like factors, including peptides, biogenic amines and neuropeptides also appear to play important roles in the regulation of insect parental care. These include biogenic amines such as dopamine, a highly conserved molecule long known to regulate parental care in vertebrates and increasingly investigated in insects [46–50], as well as neuropeptides like inotocin, the insect homolog of the oxytocin/vasopressin system in vertebrates [51,52]. While inotocin has been mostly studied in the context of water balance regulation, its vertebrate homologs, oxytocin and vasopressin, are well characterized for their involvement in social behaviors, including multiple aspects of parental care.

Overall, these limited data highlight that our current understanding of the endocrine regulation of parental in insects is based on a handful of species (compared to the tens of thousands exhibiting parental care) and a narrow subset of behaviors within the broader diversity of care strategies [27]. Although this bias inherently limits our ability to assess the effects of EDCs on insect parental care, it also creates opportunities for rapid and impactful discoveries. JH, dopamine, and inotocin represent promising starting points for investigating the endocrine regulation of insect parental care, while also emphasizing the complexity of drawing direct functional parallels between vertebrates and invertebrates. Importantly, this limited knowledge call for further exploration of these few known factors, their interactions, and their integration with other physiological regulatory pathways. For instance, juvenile hormone (JH) not only regulates aggression and resource defense in *N. vespilloides*, but also synchronizes reproductive and parental efforts by inhibiting male copulation through

pheromonal signaling, ensuring coordinated parental investment [53]. Building on these known candidates, -omics approaches could further expand our understanding by enabling unbiased identification of additional regulators of care - such as the seven new neuropeptides recently detected in burying beetles [54] - which can then be directly tested through functional analyses.

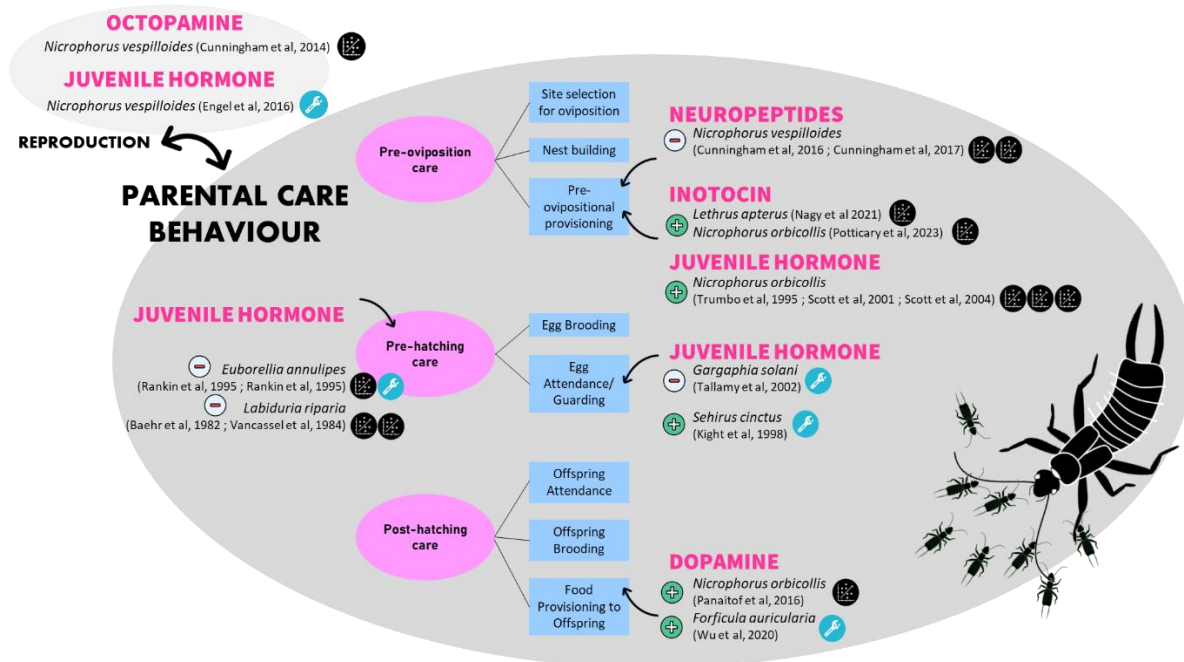


Figure 1. Hormonal factors involved in several forms of parental care. Correlational studies measuring hormone levels in relation to different caregiving situations are indicated by a graph symbol in a black circle, while experimental studies manipulating hormone levels are represented by a wrench symbol in a blue background circle. The references indicated in this figure are, from top to bottom and from left to right, as follows [49–54,75–85]

EFFECTS OF CHEMICAL COMPOUNDS ON THE REGULATION OF PARENTAL CARE IN INSECTS

While our current understanding of the hormonal regulation of parental care in insects remains limited, a few studies have begun to investigate how potential endocrine-disrupting chemicals (EDCs) may affect these behaviours. This recent research builds on a growing number of other works showing that exposure to molecules considered EDCs in vertebrates (including phthalates, bisphenols, and heavy metals) is linked to a wide range of alterations in insects, including metabolic and developmental alterations, behavioral changes, and modifications of gene expression (see Table 2) [21,55–63]. Several studies have also examined the effects of being exposed to multiple EDC mixtures, highlighting their potential cumulative impacts on insect development and physiology [55,64,65].

To the best of our knowledge, the only investigations to date addressing the impact of a known vertebrate EDC on parental care in insects has focused on cadmium, reporting no detectable effect in the European earwig [66,67]. This underlines that the potential influence of EDC-induced hormonal disruptions on insect parental care remains virtually unexplored. Beyond vertebrate EDCs, several studies have promisingly examined the effects of pesticides on insect parental care, with some reporting impaired care [68–71] and others observing no detectable effects [72]. However, in all cases, it is still unknown whether these outcomes are driven by disruptions of the hormonal pathways that regulate parental behaviors (see Table 1). Together, these limited data indicate that although several molecules are known to interfere with insect hormonal pathways and others to affect parental care, whether and how insect parental care itself is affected by EDCs remains largely uncharted. Given the central role of parental care in many insect species with economic, agricultural, and public health significance, this profound knowledge gap represents a highly promising frontier for research, with important implications not only for understanding how chemical pollutants may threaten insect populations and ecosystem stability, but also for elucidating the evolutionary dynamics of parental care under environments increasingly impacted by chemical pollution and other anthropogenic stressors.

CONCLUSION: CALL FOR FUTURE WORK ON THE HORMONAL REGULATION OF CARE IN INSECTS TO BETTER ENVISION THE IMPACT OF CHEMICAL POLLUTION ON INSECT BIODIVERSITY

Although investigating the effects of EDCs on insect parental care represents a highly promising and virtually unexplored frontier, meaningful progress cannot be achieved without substantial advancements in our understanding of the hormonal regulation of these behaviours. To address this challenge, future research should pursue five complementary priorities.

First, researchers studying parental care (e.g., behavioural ecologists and ethologists) must collaborate with endocrinologists to unravel the hormonal mechanisms underlying these behaviours, and tackle fundamental questions, such as whether a single hormonal pathway regulates all forms of parental behavior exhibited by a single species, or whether multiple hormones act in concert to shape the broader parental care phenotype.

Second, researchers need to adopt unbiased approaches to expand understanding beyond the few classical insect hormones. -Omics approaches, such as transcriptomics or proteomics, are likely to soon provide a cost-effective means to identify novel candidate pathways and regulators without prior assumptions [51,52]. Regardless of the targets or pathways revealed, subsequent functional studies (including RNAi, hormonal manipulations, CRISPR/Cas9, or mutant analyses) will be essential to establish direct causal links between specific hormones and parental behaviors.

Third, complementary to unbiased approaches, future work could rapidly expand our understanding of parental care regulation by identifying which EDCs are most likely to disrupt parental care in insects. Chemicals with well-characterized mechanisms of action, such as insect growth regulators (IGRs) that mimic or antagonize juvenile hormone, offer tractable starting points, simultaneously informing both hormonal regulation and endocrine disruption. Pesticides known to affect dopaminergic disruption in vertebrates (e.g., those implicated in Parkinson's disease [73]) may also reveal conserved mechanisms affecting parental care. Likewise, EDCs documented to impair parental care in mammals could uncover conserved

regulatory pathways in insects, for instance through shared hormone receptors [74]. Beyond targeted approaches, high-throughput molecular screening using hormone receptors coupled with reporter systems could identify new classes of chemicals with disruptive potential.

Fourth, there is an urgent need to investigate and quantify a broader range of parental care behaviours (e.g., provisioning, protection, thermoregulation) across a wider diversity of insect species. Current knowledge is largely restricted to a handful of model systems and associated forms of care, limiting our ability to generalize findings. With more than 50,000 insect species known to exhibit parental care [27], expanding the taxonomic and behavioural scope is critical to understanding the diversity of hormonal regulation and its susceptibility to disruption.

Fifth, it is critical to determine how variation or disruption in insect parental care scales from individuals to populations. Parental care is generally thought to have evolved and be maintained because it buffers offspring against biotic and abiotic risks [24]. Experimental studies in insects such as burying beetles and earwigs have shown that reduced or absent care drastically lowers offspring survival and reproductive success [35,36]. Long-term studies in vertebrates further demonstrate that variation in parental investment influences population growth and persistence [37,38]. Comparable studies in insects are urgently needed to anticipate the broader ecological consequences of parental care disruption under increasing anthropogenic pressures.

By addressing these five priorities, the field can move from correlative observations to establishing causal links between hormones, behaviour, chemical exposure, and population dynamics. This integrated approach promises not only to clarify how EDCs threaten insect populations and ecosystem stability but also to advance fundamental knowledge of the evolution and regulation of parental care in insects. Given the ecological, agricultural, and public health significance of these behaviours, this represents a highly promising and urgent frontier for research.

Acknowledgements

We sincerely thank the anonymous reviewers for their thoughtful and constructive comments, which greatly improved the clarity, structure, and overall quality of this manuscript. Their suggestions helped us refine our arguments, enhance the presentation of data, and better highlight the key research priorities in the study of hormonal regulation and endocrine disruption in insect parental care. The authors used IA software for English language editing of the manuscript.

REFERENCES

1. Harvey JA, Tougeron K, Gols R, Heinen R, Abarca M, Abram PK, Basset Y, Berg M, Boggs C, Brodeur J, et al.: **Scientists’ warning on climate change and insects.** *Ecol Monogr* 2023, **93**:e1553.
2. Wagner DL: **Insect Declines in the Anthropocene.** *Annu Rev Entomol* 2020, **65**:457–480.
3. Wagner DL, Grames EM, Forister ML, Berenbaum MR, Stopak D: **Insect decline in the Anthropocene: Death by a thousand cuts.** *Proc Natl Acad Sci* 2021, **118**:e2023989118.
4. Zhou W, Li M, Achal V: **A comprehensive review on environmental and human health impacts of chemical pesticide usage.** *Emerg Contam* 2025, **11**:100410.
5. Aktar W, Sengupta D, Chowdhury A: **Impact of pesticides use in agriculture: their benefits and hazards.** *Interdiscip Toxicol* 2009, **2**:1–12.
6. World Health Organization (WHO): *Global assessment of the state-of-the-science of endocrine disruptors.* WHO; 2002.
7. Marlatt VL, Bayen S, Castaneda-Cortès D, Delbès G, Grigorova P, Langlois VS, Martyniuk CJ, Metcalfe CD, Parent L, Rwigemera A, et al.: **Impacts of endocrine disrupting chemicals on reproduction in wildlife and humans.** *Environ Res* 2022, **208**:112584.
8. Cuvillier-Hot V, Lenoir A: **Invertebrates facing environmental contamination by endocrine disruptors: Novel evidences and recent insights.** *Mol Cell Endocrinol* 2020, **504**:110712.
9. De Loof A, Schoofs L: **Homologies between the amino acid sequences of some vertebrate peptide hormones and peptides isolated from invertebrate sources.** *Comp Biochem Physiol Part B Comp Biochem* 1990, **95**:459–468.
10. Odekunle EA, Elphick MR: **Comparative and Evolutionary Physiology of Vasopressin/ Oxytocin-Type Neuropeptide Signaling in Invertebrates.** *Front Endocrinol* 2020, **11**:225.
11. Elphick MR: **Evolution of Hypothalamic–Pituitary Neuropeptides and Their Receptors: Insights from Invertebrates.** In *Evolutionary and Comparative Neuroendocrinology.* Edited by Grinevich V, Oliveira R. Springer Nature Switzerland; 2025:45–70.
12. Orchard I, Lange AB: **The neuroendocrine and endocrine systems in insect – Historical perspective and overview.** *Mol Cell Endocrinol* 2024, **580**:112108.
13. Pener MP, Dhadialla TS: **An Overview of Insect Growth Disruptors; Applied Aspects.** In *Advances in Insect Physiology.* Elsevier; 2012:1–162.
14. Jindra M, Bittova L: **The juvenile hormone receptor as a target of juvenoid “insect growth regulators.”** *Arch Insect Biochem Physiol* 2020, **103**:e21615.
15. Litsey EM, Fine JD: **Developmental exposure to hormone-mimicking insect growth disruptors alters expression of endocrine-related genes in worker honey bee (Hymenoptera: Apidae) brains and hypopharyngeal glands.** *J Econ Entomol* 2024, **117**:377–387.
16. Ford AT, Ågerstrand M, Brooks BW, Allen J, Bertram MG, Brodin T, Dang Z, Duquesne S, Sahm R, Hoffmann F, et al.: **The Role of Behavioral Ecotoxicology in Environmental Protection.** *Environ Sci Technol* 2021, **55**:5620–5628.
17. Alla LNR, Monshi M, Siddiqua Z, Shields J, Alame K, Wahls A, Akemann C, Meyer D, Crofts EJ, Saad F, et al.: **Detection of endocrine disrupting chemicals in *Danio rerio* and *Daphnia pulex*: Step-one, behavioral screen.** *Chemosphere* 2021, **271**:129442.
18. Bakoyiannis I, Kitraki E, Stamatakis A: **Endocrine-disrupting chemicals and behaviour: A high risk to take?** *Best Pract Res Clin Endocrinol Metab* 2021, **35**:101517.

19. Hartman CA, Ackerman JT, Herzog MP: **Mercury Exposure and Altered Parental Nesting Behavior in a Wild Songbird.** *Environ Sci Technol* 2019, **53**:5396–5405.
20. Mhaouty-Kodja S, Naulé L, Capela D: **Sexual Behavior: From Hormonal Regulation to Endocrine Disruption.** *Neuroendocrinology* 2018, **107**:400–416.
21. Song Y, Zhang X, Wang B, Luo X, Zhang K, Zhang X, Wu Q, Sun M: **BPAP induces autism-like behavior by affecting the expression of neurodevelopmental genes in *Drosophila melanogaster*.** *Ecotoxicol Environ Saf* 2024, **288**:117405.
22. Zala SM, Penn DJ: **Abnormal behaviours induced by chemical pollution: a review of the evidence and new challenges.** *Anim Behav* 2004, **68**:649–664.
23. Meunier J, Körner M, Kramer J: **Parental Care.** In *Reproductive Strategies in Insects.* . CRC Press; 2022:337–357.
24. Kramer J, Meunier J: **The other facets of family life and their role in the evolution of animal sociality.** *Biol Rev* 2019, **94**:199–215.
25. Machado G, Trumbo ST: **Parental care.** In *Insect Behavior: From Mechanisms to Ecological and Evolutionary Consequences.* Edited by Córdoba-Aguilar A, González-Tokman D, González-Santoyo I. Oxford University Press; 2018:0.
26. Wong JWY, Meunier J, Kölliker M: **The evolution of parental care in insects: the roles of ecology, life history and the social environment.** *Ecol Entomol* 2013, **38**:123–137.
27. Meunier J, Körner M, Kramer J: **Parental care.** In *Reproductive Strategies in Insects.* Edited by Omkar, Mishra G. CRC Press; 2022:337–348.
28. Honorio R, Cheutin M –C., Pasquier L, De Wever S, Perdereau E, Villalta I, Lécureuil C, Meunier J: **The European earwig: a model species for studying the (early) evolution of social life.** *Insectes Sociaux* 2024, doi:10.1007/s00040-024-00985-0.
29. Potticary AL, Belk MC, Creighton JC, Ito M, Kilner R, Komdeur J, Royle NJ, Rubenstein DR, Schrader M, Shen S-F, et al.: **Revisiting the ecology and evolution of burying beetle behavior (Staphylinidae: Silphinae).** *Ecol Evol* 2024, **14**:e70175.
30. Ratz T: **Burying beetles as a model organism to study sex differences in parental care.** *Insectes Sociaux* 2024, doi:10.1007/s00040-024-01010-0.
31. Meunier J: **The biology and social life of earwigs (Dermaptera).** *Annu Rev Entomol* 2024, **69**:259–276.
32. Klug H, Bonsall MB: **What are the benefits of parental care? The importance of parental effects on developmental rate.** *Ecol Evol* 2014, **4**:2330–2351.
33. Thesing J, Kramer J, Koch LK, Meunier J: **Short-term benefits, but transgenerational costs of maternal loss in an insect with facultative maternal care.** *Proc R Soc Lond B Biol Sci* 2015, **282**:20151617.
34. Kramer J, Meunier J: **The other facets of family life and their role in the evolution of animal sociality.** *Biol Rev* 2019, **94**:199–215.
35. Eggert A-K, Reinking M, Müller JK: **Parental care improves offspring survival and growth in burying beetles.** *Anim Behav* 1998, **55**:97–107.
36. Meunier J, Kölliker M: **When it is costly to have a caring mother: food limitation erases the benefits of parental care in earwigs.** *Biol Lett* 2012, **8**:547–550.
37. Clutton-Brock TH: *The Evolution of Parental Care.* Princeton University Press; 1991.

38. Taborsky M: **Broodcare helpers in the cichlid fish *Lamprologus brichardi*: Their costs and benefits.** *Anim Behav* 1984, **32**:1236–1252.
39. Keller M, Vandenberg LN, Charlier TD: **The parental brain and behavior: A target for endocrine disruption.** *Front Neuroendocrinol* 2019, **54**:100765.
40. Paris OJ, Swaddle JP, Cristol DA: **Exposure to Dietary Methyl-Mercury Solely during Embryonic and Juvenile Development Halves Subsequent Reproductive Success in Adult Zebra Finches.** *Environ Sci Technol* 2018, **52**:3117–3124.
41. Laaroussi M, Boukholda K, Essaidi O, Berroug L, Malqui H, Anarghou H, Fetoui H, Chigr F: **Multigenerational impact of chronic exposure to mercury chloride on maternal care, puberty, fertility, and hypothalamic function in female mice.** *Environ Res* 2025, **264**:120396.
42. López-Rodríguez D, Aylwin CF, Delli V, Sevrin E, Campanile M, Martin M, Franssen D, Gérard A, Blacher S, Tirelli E, et al.: **Multi- and Transgenerational Outcomes of an Exposure to a Mixture of Endocrine-Disrupting Chemicals (EDCs) on Puberty and Maternal Behavior in the Female Rat.** *Environ Health Perspect* 2021, **129**:087003.
43. Jindra M, Palli SR, Riddiford LM: **The Juvenile Hormone Signaling Pathway in Insect Development.** *Annu Rev Entomol* 2015, **58**:181–204.
44. Leyria J, Orchard I, Lange AB: **Impact of JH Signaling on Reproductive Physiology of the Classical Insect Model, *Rhodnius prolixus*.** *Int J Mol Sci* 2022, **23**:13832.
45. Riddiford LM: **Rhodnius, Golden Oil, and Met: A History of Juvenile Hormone Research.** *Front Cell Dev Biol* 2020, **8**:679.
46. Bloch G, Simon T, Robinson GE, Hefetz A: **Brain biogenic amines and reproductive dominance in bumble bees (*Bombus terrestris*).** *J Comp Physiol [A]* 2000, **186**:261–268.
47. Boulay R, Hooper-Bui LM, Woodring J: **Oviposition and oogenesis in virgin fire ant females *Solenopsis invicta* are associated with a high level of dopamine in the brain.** *Physiol Entomol* 2001, **26**:294–299.
48. Gruntenko NE, Khlebodarova TM, Vasenkova IA, Sukhanova MJ, Wilson TG, Rauschenbach IY: **Stress-reactivity of a *Drosophila melanogaster* strain with impaired juvenile hormone action.** *J Insect Physiol* 2000, **46**:451–456.
49. Panaitof SC, Yaeger JDW, Speer JP, Renner KJ: **Biparental behavior in the burying beetle *Nicrophorus orbicollis* : a role for dopamine?** *Curr Zool* 2016, **62**:285–291.
50. Wu M, Walser J-C, Sun L, Kölliker M: **The genetic mechanism of selfishness and altruism in parent-offspring coadaptation.** *Sci Adv* 2020, **6**:eaaw0070.
51. Nagy NA, Németh Z, Juhász E, Póliska S, Rác R, Kiss J, Kosztolányi A, Barta Z: **Inotocin, a potential modulator of reproductive behaviours in a biparental beetle, *Lethrus apterus*.** *J Insect Physiol* 2021, **132**:104253.
52. Potticary AL, Cunningham CB, McKinney EC, Moore PJ, Belay AT, Moore AJ: **Insect homolog of oxytocin/vasopressin associated with parenting of males but not females in a subsocial beetle.** *Evolution* 2023, **77**:2029–2038.
53. Engel KC, Stökl J, Schweizer R, Vogel H, Ayasse M, Ruther J, Steiger S: **A hormone-related female anti-aphrodisiac signals temporary infertility and causes sexual abstinence to synchronize parental care.** *Nat Commun* 2016, **7**:11035.
54. Cunningham CB, Badgett MJ, Meagher RB, Orlando R, Moore AJ: **Ethological principles predict the neuropeptides co-opted to influence parenting.** *Nat Commun* 2017, **8**:14225.

55. Frat L, Chertemps T, Pesce E, Bozzolan F, Dacher M, Planelló R, Herrero O, Llorente L, Moers D, Siaussat D: **Single and mixed exposure to cadmium and mercury in *Drosophila melanogaster*: Molecular responses and impact on post-embryonic development.** *Ecotoxicol Environ Saf* 2021, **220**:112377.
56. Planelló R, Herrero O, Martínez-Guitarte JL, Morcillo G: **Comparative effects of butyl benzyl phthalate (BBP) and di(2-ethylhexyl) phthalate (DEHP) on the aquatic larvae of *Chironomus riparius* based on gene expression assays related to the endocrine system, the stress response and ribosomes.** *Aquat Toxicol* 2011, **105**:62–70.
57. Williams MJ, Wiemerslage L, Gohel P, Kheder S, Kothegeala LV, Schiöth HB: **Dibutyl Phthalate Exposure Disrupts Evolutionarily Conserved Insulin and Glucagon-Like Signaling in *Drosophila* Males.** *Endocrinology* 2016, **157**:2309–2321.
58. Aviles A, Boulogne I, Durand N, Maria A, Cordeiro A, Bozzolan F, Goutte A, Alliot F, Dacher M, Renault D, et al.: **Effects of DEHP on post-embryonic development, nuclear receptor expression, metabolite and ecdysteroid concentrations of the moth *Spodoptera littoralis*.** *Chemosphere* 2019, **215**:725–738.
59. Maria A, Malbert-Colas A, Boulogne I, Braman V, Boitard C, Dacher M, Chertemps T, Maibeche M, Blais C, Siaussat D: **Effects of bisphenol A on post-embryonic development of the cotton pest *Spodoptera littoralis*.** *Chemosphere* 2019, **235**:616–625.
60. Planelló R, Martínez-Guitarte JL, Morcillo G: **The endocrine disruptor bisphenol A increases the expression of HSP70 and ecdysone receptor genes in the aquatic larvae of *Chironomus riparius*.** *Chemosphere* 2008, **71**:1870–1876.
61. Herrero Ó, Aquilino M, Sánchez-Argüello P, Planelló R: **The BPA-substitute bisphenol S alters the transcription of genes related to endocrine, stress response and biotransformation pathways in the aquatic midge *Chironomus riparius* (Diptera, Chironomidae).** *PLOS ONE* 2018, **13**:e0193387.
62. Wang J, Wu C, Zhang X, Song Y, Wang B, Zhang K, Sun M: **Developmental neurotoxic effects of bisphenol A and its derivatives in *Drosophila melanogaster*.** *Ecotoxicol Environ Saf* 2023, **260**:115098.
63. Su H, Yang Y, Zou J, Cheng Y, Yang Y, Wu J, Pollak P, Yang Y: **Transcriptome analysis of the ovary of beet armyworm *Spodoptera exigua* under different exposures of cadmium stress.** *Chemosphere* 2020, **251**:126372.
64. Frat L, Chertemps T, Pesce E, Bozzolan F, Dacher M, Planello R, Herrero O, Llorente L, Moers D, Siaussat D: **Impact of single and combined exposure to priority pollutants on gene expression and post-embryonic development in *Drosophila melanogaster*.** *Ecotoxicol Environ Saf* 2023, **250**:114491.
65. Rivas J, Fuentes A, Maria A, Bergerot B, Siaussat D, Renault D: **Effects of phthalate and bisphenol plasticizers on the activity of glycolytic enzymes of the moth *Spodoptera littoralis*.** *J Insect Physiol* 2023, **149**:104533.
66. Honorio R, Depierrefixe P, Devers S, Rouelle M, Meunier J, Lécureuil C: **Effects of cadmium ingestion on reproduction and maternal egg care in the European earwig.** *Anim Behav* 2023, **195**:1–8.
67. Honorio R, Moreau S, Lécureuil C, Meunier J: **Cadmium does not affect post-hatching maternal care or early offspring development in earwigs.** *Behav Ecol* 2023, **34**:399–407.
68. Meunier J, Dufour J, Van Meyel S, Rault M, Lécureuil C: **Sublethal exposure to deltamethrin impairs maternal egg care in the European earwig *Forficula auricularia*.** *Chemosphere* 2020, **258**:127383.

69. Mauduit E, Lécureuil C, Meunier J: **Sublethal exposure to deltamethrin stimulates reproduction and has limited effects on post-hatching maternal care in the European earwig.** *Environ Sci Pollut Res* 2021, **28**:39501–39512.
70. Chole H, De Guinea M, Woodard SH, Bloch G: **Field-realistic concentrations of a neonicotinoid insecticide influence socially regulated brood development in a bumblebee.** *Proc R Soc B Biol Sci* 2022, **289**:20220253.
71. Leza M, Watrous KM, Bratu J, Woodard SH: **Effects of neonicotinoid insecticide exposure and monofloral diet on nest-founding bumblebee queens.** *Proc R Soc B Biol Sci* 2018, **285**:20180761.
72. Merleau L-A, Larrigaldie I, Bousquet O, Devers S, Keller M, Lécureuil C, Meunier J: **Exposure to pyriproxyfen (juvenile hormone agonist) does not alter maternal care and reproduction in the European earwig.** *Environ Sci Pollut Res* 2022, **29**:72729–72746.
73. Paul KC, Krolewski RC, Lucumi Moreno E, Blank J, Holton KM, Ahfeldt T, Furlong M, Yu Y, Cockburn M, Thompson LK, et al.: **A pesticide and iPSC dopaminergic neuron screen identifies and classifies Parkinson-relevant pesticides.** *Nat Commun* 2023, **14**:2803.
74. Sladek FM: **What are nuclear receptor ligands?** *Mol Cell Endocrinol* 2011, **334**:3–13.
75. Cunningham CB, Douthit MK, Moore AJ: **Octopaminergic gene expression and flexible social behaviour in the subsocial burying beetle *Nicrophorus vespilloides*.** *Insect Mol Biol* 2014, **23**:391–404.
76. Rankin SM, Palmer JO, Yagi KJ, Scott GL, Tobet SS: **Biosynthesis and release of juvenile hormone during the reproductive cycle of the ring-legged earwig.** *Comp Biochem Physiol C Pharmacol Toxicol Endocrinol* 1995, **110**:241–251.
77. Rankin SM, Fox KM, Stotsky CE: **Physiological correlates to courtship, mating, ovarian development and maternal behaviour in the ring-legged earwig.** *Physiol Entomol* 1995, **20**:257–265.
78. Baehr JCI, Cassier P, Caussanel CI, Porcheron P: **Activity of corpora allata, endocrine balance and reproduction in female *Labidura riparia* (Dermaptera).** *Cell Tissue Res* 1982, **225**.
79. Vancassel M, Foraste M, Strambi A, Strambi C: **Normal and experimentally induced changes in hormonal hemolymph titers during parental behavior of the earwig *Labidura riparia*.** *Gen Comp Endocrinol* 1984, **56**:444–456.
80. Cunningham CB, VanDenHeuvel K, Khana DB, McKinney EC, Moore AJ: **The role of neuropeptide F in a transition to parental care.** *Biol Lett* 2016, **12**:20160158.
81. Trumbo ST, Borst DW, Robinson GE: **Rapid elevation of juvenile hormone titer during behavioral assessment of the breeding resource by the burying beetle, *Nicrophorus orbicollis*.** *J Insect Physiol* 1995, **41**:535–543.
82. Scott MP, T. Trumbo S, Neese PA, Bailey WD, Roe RM: **Changes in biosynthesis and degradation of juvenile hormone during breeding by burying beetles: a reproductive or social role?** *J Insect Physiol* 2001, **47**:295–302.
83. Scott MP, Panaitof SC: **Social stimuli affect juvenile hormone during breeding in biparental burying beetles (Silphidae: Nicrophorus).** *Horm Behav* 2004, **45**:159–167.
84. Tallamy DW, Monaco EL, Pesek JD: **Hormonal Control of Egg Dumping and Guarding in the Lace Bug, *Gargaphia solani* (Hemiptera: Tingidae).** *J Insect Behav* 2002, **15**:467–475.
85. Kight SL: **Precocene II modifies maternal responsiveness in the burrower bug, *Sehirus cinctus* (Heteroptera).** *Physiol Entomol* 1998, **23**:38–42.

SELECTED REFERENCES

Song et al., 2024 ●

Using a *Drosophila* model, this study examines the neurodevelopmental toxicity of Bisphenol AP (BPAP). The findings reveal that BPAP exposure disrupts growth, induces autism-like behaviors, and impairs neurogenesis by affecting estrogen signaling and neurodevelopment-related gene expression. These results suggest BPAP may contribute to neurodevelopmental disorders.

Laaroussi, 2025 ●

This study explores the long-term consequences of chronic low-dose mercury exposure on female reproductive health and maternal behavior in mice. Across generations, mercury exposure alters reproductive traits, delaying puberty, disrupting estrous cycles, and reducing mating interest. These effects correlate with hypothalamic gene expression changes and increased inflammatory markers, pointing to neuroendocrine and immune system disruptions.

Litsey et al., 2024 ●●

Investigating the impact of insect-growth disruptors (IGDs) on honey bees, this study shows that while IGDs do not significantly affect gland or ovary development, they alter gene expression linked to reproduction and endocrine signaling. These findings suggest IGDs may influence colony stability by modifying worker responses to queen pheromones.

Orchard, 2024 ●●

Focusing on the neuroendocrine and endocrine systems in insects, this review examines their role in regulating behavioral plasticity. By integrating historical perspectives with modern research, it explores how neurohormones and hormones mediate behavioral transitions. The discussion extends to peripheral tissues that contribute to hormonal signaling, further emphasizing inter-organ communication.

Honorio, 2024 ●

The European earwig serves as a key model for studying social evolution beyond eusocial insects. This review explores its life cycle, social behaviors, and the balance between conflict and cooperation. It also examines the influence of pathogens, environmental changes, and molecular regulation on facultative sociality, offering new perspectives on the evolution of group living.

Potticay, 2024 ●

Burying beetles (*Nicrophorus*) are among the most extensively studied models for parental care regulation in insects. This review synthesizes recent findings on their behavior, ecology, and evolution, emphasizing their role in advancing research on social and reproductive strategies. Their behavioral diversity and ecological significance reinforce their value as a model system for understanding parental investment.

Meunier, 2024 ●●

Although earwigs are often overlooked in studies of insect sociality, they exhibit a remarkable diversity of group living and parental care strategies. This review examines their

ability to transition between solitary and social living, shedding light on the early evolutionary pathways leading to insect sociality.

Harvey, 2023 ●

Climate change poses a significant threat to insect biodiversity, affecting physiology, behavior, and ecosystem dynamics. This review synthesizes current knowledge on gradual warming and extreme climatic events, emphasizing the urgent need for conservation strategies. It also outlines key policy recommendations and management approaches to mitigate these threats and preserve essential ecosystem services.

Table 1: Effects of Hormones on Parental Care in Insects

Hormone	Effect on parental care	Species	Observation	Ref.
JH	Inhibits care	<i>Euborellia annulipes</i> <i>Labidura riparia</i>	JH levels naturally decline during life-cycle phases associated with parental egg care	[76,78,79]
JH	Inhibits care	<i>Euborellia annulipes</i>	JH exposure reduced the duration of maternal egg care	[77]
JH	Inhibits care	<i>Gargaphia solani</i>	females treated with a JH inhibitor (precocene) ceased egg dumping and adopted guarding behaviours, whereas those treated with a JH analog (methoprene) became gravid and abandoned their eggs	[84]
JH	Promotes care	<i>Nicrophorus orbicollis</i>	periods of intensified care correlate with elevated JH levels in mothers, including indirect care such as defense of food resources	[53,81–83]
JH	Promotes care	<i>Sehirus cinctus</i>	precocene II treatment reduced maternal defense, but co-treatment with methoprene restored the defensive phenotype, confirming JH's involvement in parental care	[85]
Dopamine	Promotes care (feeding)	<i>N. vespilloides</i>	Dopamine levels correlate with parental feeding	[49]
Dopamine	Promotes care (feeding)	<i>Forficula auricularia</i>	knockdown of tyrosine hydroxylase, a key enzyme in dopamine synthesis, reduces the level of maternal food provisioning to juveniles	[50]
Dopamine	Modulates care via JH	<i>Various insects</i>	Dopamine also controls JH level and ovarian development	[46–48]
Inotocin	Linked to parental food provisioning	<i>N. orbicollis</i>	Inotocin involved in parental food provisioning	[51,52]
Neuropeptide F	Linked to parental food provisioning	<i>N. vespilloides</i>	Influences feeding, motivation and stress responses	[54,80]

Table 2: Representative cases of endocrine-disrupting compounds tested in insects and their observed outcomes

Tested molecule	Species	Observed effects	Ref.
BBP, DEHP (phthalates)	<i>Chironomus riparius</i>	Disruption of endocrine signaling in larvae	[56]
DBP (dibutyl phthalate)	<i>Drosophila melanogaster</i>	Metabolic dysfunction	[57]
DEHP	<i>Spodoptera littoralis</i>	Effects on behavior and offspring viability	[58]
BPA (bisphenol A)	<i>Spodoptera littoralis</i>	Disruption of ecdysteroid signaling	[59]
BPA	<i>Chironomus riparius</i>	EcR overexpression	[61]
BPS (bisphenol S)	<i>Drosophila sp.</i>	Neurodevelopmental and behavioral impacts Upregulation of hormone-related genes	[57]
Cadmium	<i>Spodoptera exigua</i>	Effects on ovarian gene expression	[63]
Cadmium	<i>Drosophila melanogaster</i>	Developmental delays and gene deregulation	[55]
Mixtures (BPA, DEHP, cadmium, mercury)	<i>Drosophila melanogaster</i>	Developmental delays, mortality, and changes in gene expression	[55,64]
Cadmium	<i>Forficula auricularia</i>	No effect on parental care	[66,67]
Neonicotinoids	<i>Bombus sp.</i> (bumblebees)	Reduced queen activity and brood care, affecting colony development and reproductive success	[70,71]
Deltamethrin	<i>Forficula auricularia</i>	Impaired maternal behaviors (egg gathering and brood defense)	[68,69]
Pyriproxyfen (JH agonist)	<i>Forficula auricularia</i>	No effect on egg and nymph care (likely due to naturally high JH levels during this period)	[72]