## Supplementary File S3

# A Global Meta-Analysis Reveals the Toxicity of Plastics on Insect Health


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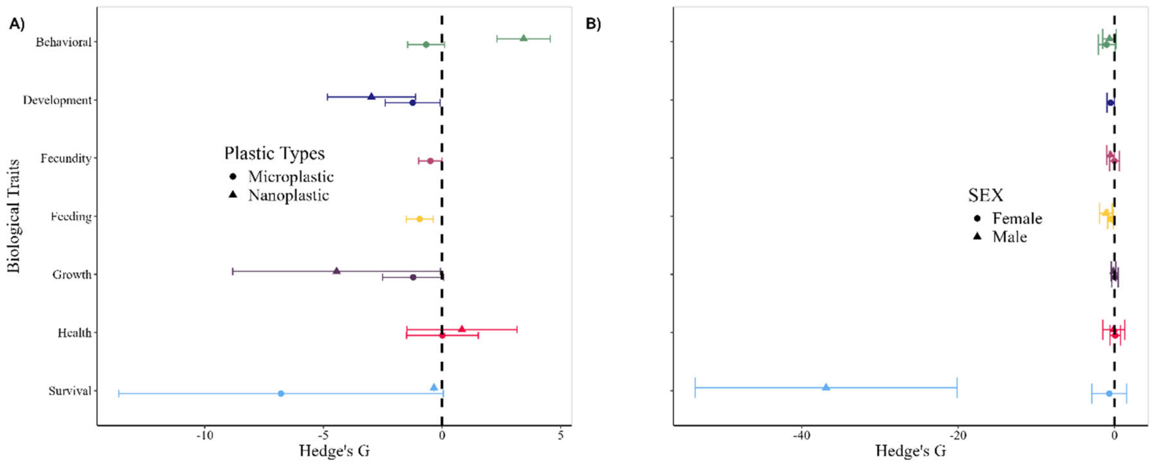
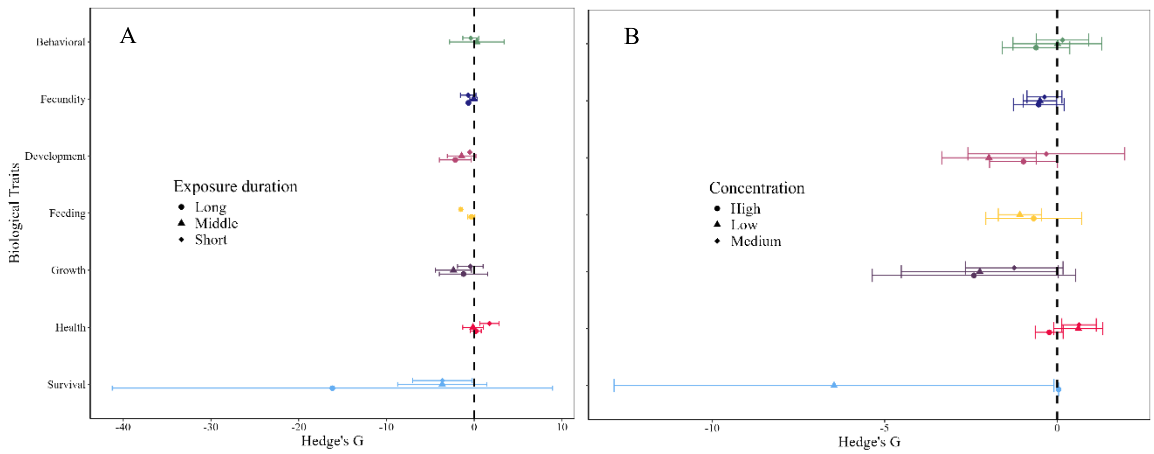
**Figure S2: Impact of Plastics on Insect Biological Traits by Plastic Type and Sex**




The effects of plastics on insect biological traits show distinct trends depending on the type of plastic and the sex of the insects. **Panel A** highlights how nanoplastics (represented by triangles) generally have stronger negative effects across biological traits, like behavior, development, and growth, compared to microplastics (represented by circles). Both plastic types significantly impact growth, but nanoplastics tend to have more profound adverse effects, as seen by a larger shift in Hedge's G values. For survival, both microplastics and nanoplastics exhibit strong negative impacts, although microplastics have a more extreme effect on survival, with Hedge's G skewing toward -10. Fecundity and feeding, while affected, show more variable responses, with fecundity having minimal negative to slightly positive impacts in certain cases.

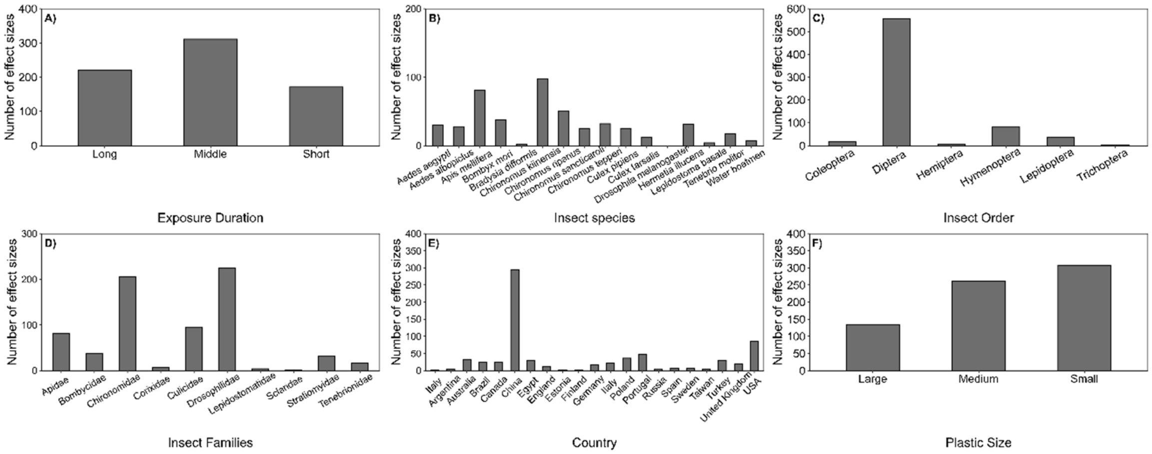
**Panel B** compares the effects of plastics based on insect sex, revealing that female insects (represented by circles) are generally more resilient across most biological traits compared to males (triangles), particularly in growth, health, and survival. Male insects show more pronounced negative impacts, especially in survival, with Hedge's G values far exceeding -40. This suggests a significant sex-based vulnerability to plastic pollution, with males being more sensitive to both micro- and nanoplastics. This differential impact may have implications for population dynamics, potentially leading to skewed sex ratios in insect populations exposed to plastic pollution.

**Figure S3: Effect of Exposure Duration and Concentration on Biological Traits of Insects**




This supplementary figure illustrates the relationship between Hedges' G effect sizes and different biological traits of insects under varying exposure conditions. Panel (A) depicts the impact of exposure duration (long, middle, and short) on traits such as behavioral, fecundity, development, feeding, growth, health, and survival. Panel (B) shows the effects of plastic concentration levels (high, medium, and low) on the same biological traits. The error bars represent the 95% confidence intervals, and the dashed vertical line at 0 represents the null effect. The trends observed in survival and health suggest pronounced impacts at certain exposure levels and durations, providing insights into the differential susceptibility of biological traits to plastic exposure.

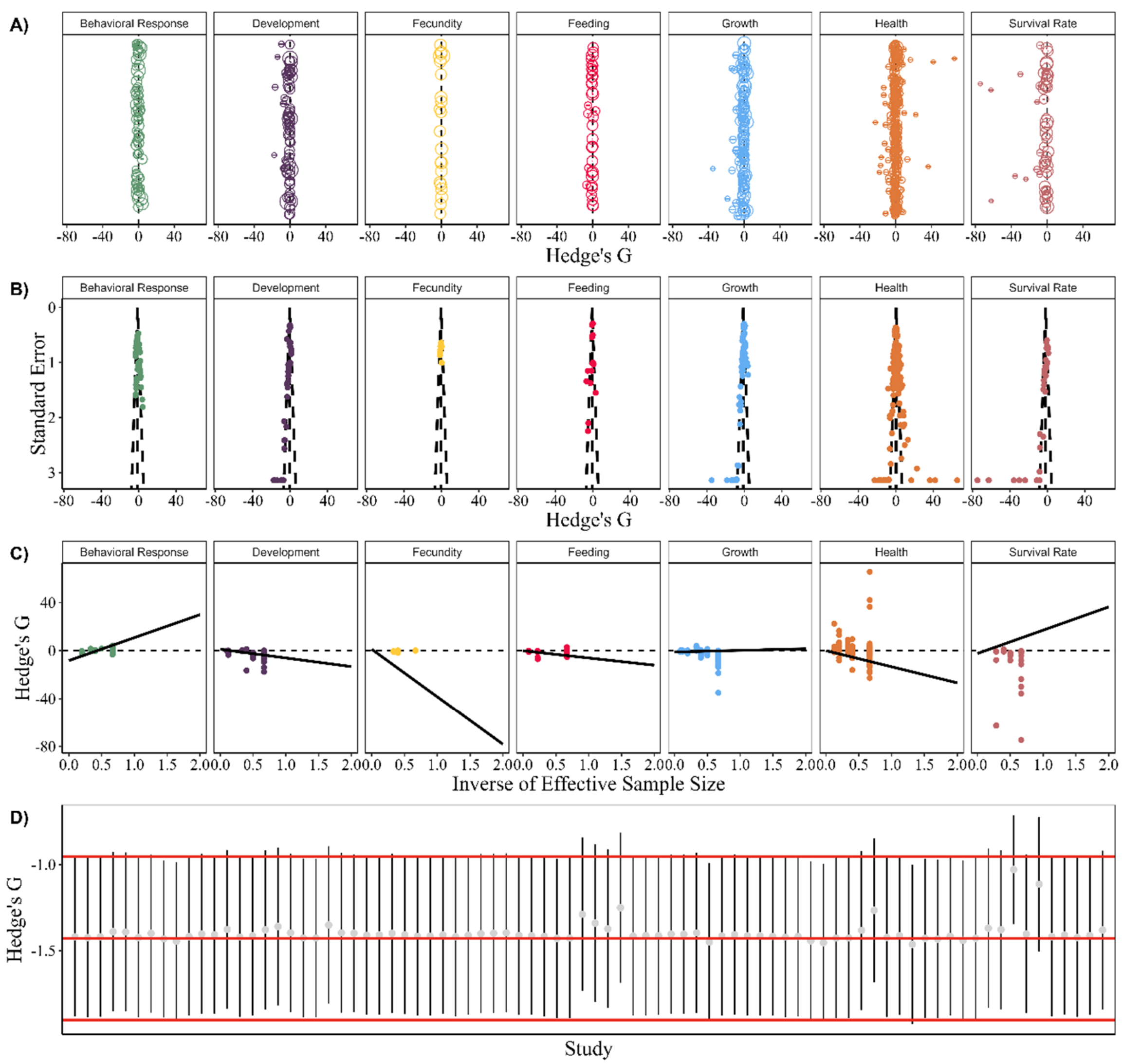
**Figure S4: Summary of the Number of Effect Sizes for Insect and Plastic Exposure Characteristics**




This figure summarizes the distribution of effect sizes across various parameters related to insect exposure to plastics. (A) Exposure duration categorized into long, middle, and short durations, showing the highest number of effect sizes in the middle duration category. (B) Insect species contributing to the database, with notable representation from Chironomus riparius and *Drosophila melanogaster*. (C) Insect orders affected, with Diptera showing the highest number of effect sizes. (D) Families within the insect taxa, with Chironomidae and Drosophilidae contributing most effect sizes. (E) Geographical distribution of studies, indicating China as the primary contributor to the dataset. (F) Plastic sizes categorized as large, medium, and small, with medium and small-sized plastics being most frequently studied.

This analysis highlights the breadth of data collected on insect-plastic interactions, emphasizing the diversity of species, exposure conditions, and global research contributions. These patterns provide a foundation for assessing the ecological implications of plastic pollution on insects across varying biological and environmental contexts.

**Figure S5: Forest Plots of Effect Sizes, Associated Variances, and Relative Weights (A), Funnel Plots (B), and Egger's Test Plots (C) for Each Response Variable and Leave-One-Out Sensitivity Analyses (D)**



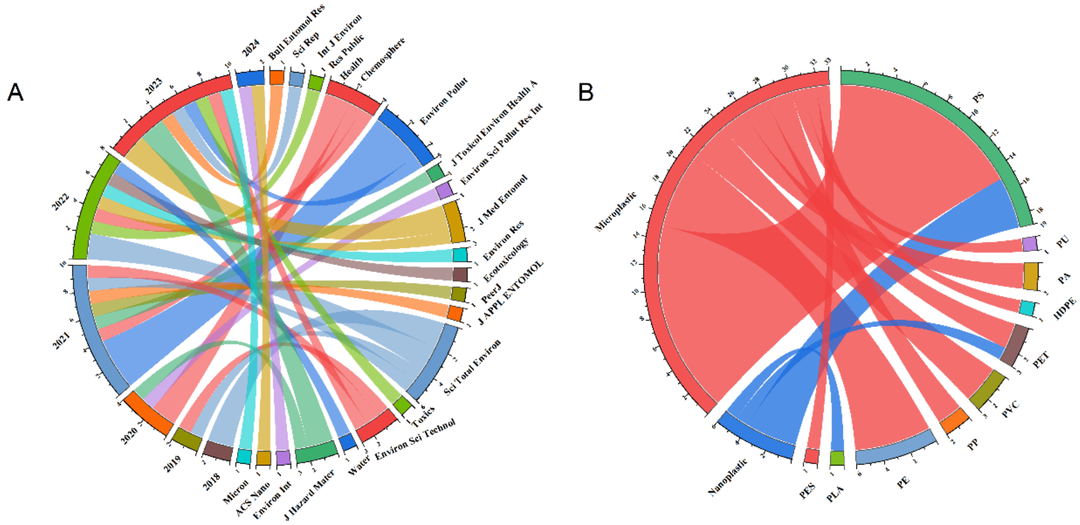

In **Panel A**, the points represent individual effect sizes (Hedge's G) across different response variables, including Behavioral Response, Development, Fecundity, Feeding, Growth, Health, and Survival Rate. Error bars show the standard errors of the effect sizes, and the size of each point indicates the relative weight of the observation in the model, with larger points representing observations with higher weight. The effect sizes are plotted in a random order.

**Panel B** shows funnel plots of Hedge's G against their standard errors for each response variable, helping to visualize the spread of the effect sizes. This plot is often used to detect publication bias, as symmetry around the mean suggests less bias. The observed asymmetries in some plots may indicate potential bias or genuine variability in the studies.

**Panel C** displays Egger's regression test plots, where Hedge's G is plotted against the inverse of the effective sample size for each response variable. The slopes and trends in these plots indicate asymmetry, with deviations from the horizontal line suggesting potential publication bias or real effect trends. Some panels exhibit slight asymmetries, which might be due to outliers or genuine effects depending on the context of the study.

**In Panel D**, the horizontal red lines represent the grand mean and standard error (SE) of Hedge's G ($g = 0.1009$, $SE = 0.0338$). Grey points with error bars indicate the Hedge's G values recalculated using a leave-one-out approach, where each point shows the effect of removing a specific study. While some studies' removal caused slight shifts, all recalculated Hedge's G values remained within the SE of the grand mean. This sensitivity analysis demonstrates that the results are robust and not overly dependent on any single study.

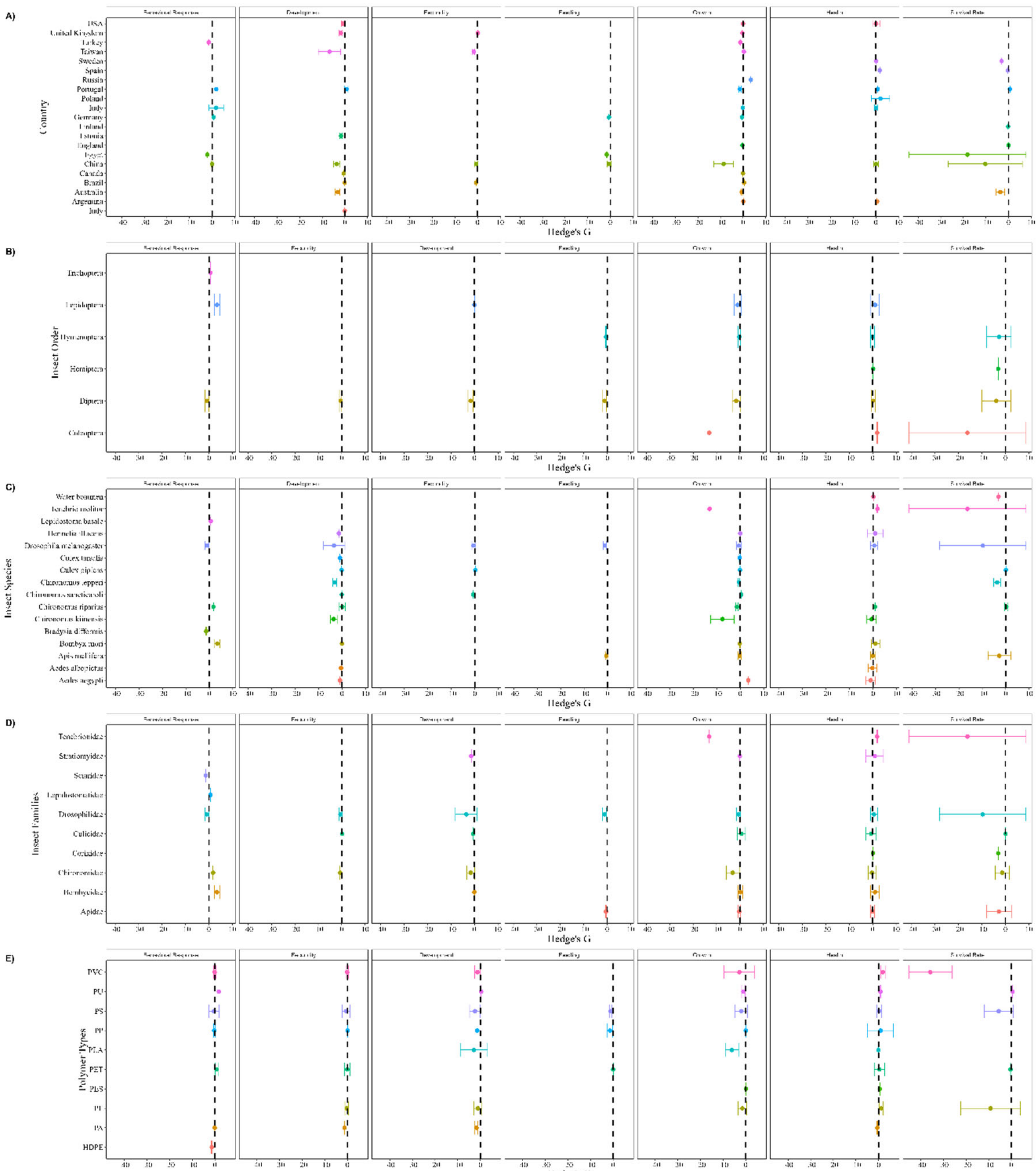
**Figure S6: Chord diagrams illustrating the distribution of research studies and plastic polymer types in micro- and nanoplastics research on insects.**



**Panel A** visualizes the chronological progression and journal-wise distribution of studies investigating the impact of micro and nanoplastics on insects from 2017 to 2024. Each segment along the circular axis represents a specific year or journal, with the size of the segment indicating the number of studies published within that year or journal. The connecting ribbons represent the flow of research between years and journals, emphasizing the expansion of this research field over time. Notably, a sharp rise in the number of studies occurred between 2022 and 2024, indicating a growing recognition of this field's importance. Prominent journals such as *Environmental Pollution*, *Chemosphere*, and *Scientific Reports* have become leading platforms for publishing related research, highlighting their central role in advancing knowledge on the ecological effects of plastics on insects.

**Panel B** illustrates the types of plastics (both micro and nano) studied in relation to their impact on insect populations. The size of each plastic type segment reflects the frequency of its study, with **Polystyrene (PS)** emerging as the most extensively researched polymer. Polymers like **Polyethylene (PE)** and **Polypropylene (PP)** also show significant representation, indicating their widespread environmental prevalence and potential impact on insect species. Microplastics are prominently featured in the research, with fewer studies focusing on nanoplastics, although the latter is gaining attention due to its ability to penetrate biological systems more deeply. The chord diagram emphasizes the current knowledge gaps, particularly in the research of lesser-studied polymers, suggesting the need for a more diversified investigation into various plastic types to comprehensively assess their ecological impact on insect populations.

**Figure S7: Meta-Analysis of the Effects of Micro- and Nanoplastics on Insect Biological Traits Across Different Categories.**




**(A)** The impact of microplastics and nanoplastics on various biological traits in insects across different countries. Biological responses such as behavior, development, fecundity, feeding, growth, health, and survival rate are plotted against Hedge's G values, with a comparison across geographical locations. Each point represents a study from a specific country, showing variability in plastic-induced effects, with some countries showing significantly more negative impacts, particularly in health and survival.

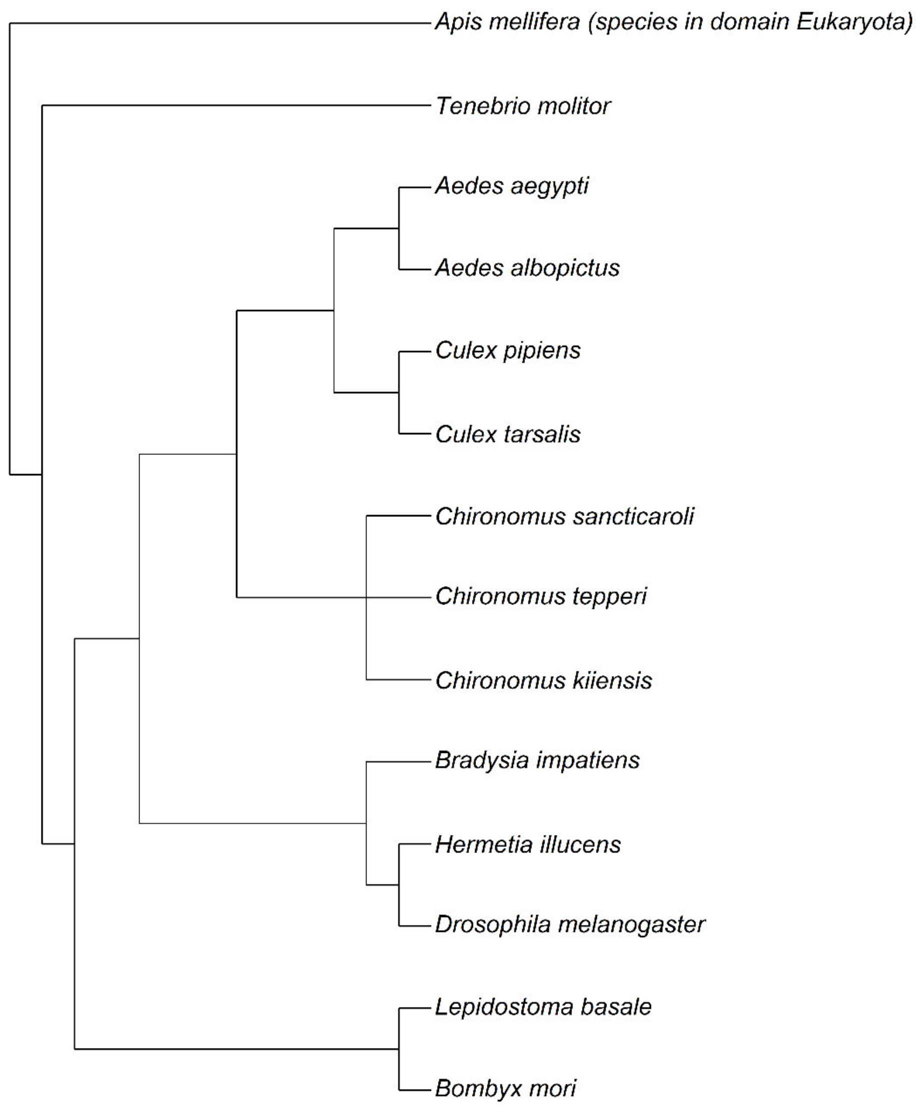
**(B)** The effects of micro- and nanoplastics across different insect orders, including Trichoptera, Lepidoptera, Hemiptera, Hymenoptera, Diptera, and Coleoptera. The data indicate that different insect orders show varied sensitivity, with some orders, such as Lepidoptera and Hymenoptera, exhibiting more adverse effects, particularly in traits like growth and survival.

**(C)** The response of different insect species to micro- and nanoplastics. This panel highlights species-specific variations, with certain species showing greater susceptibility, particularly in terms of survival and health traits. For example, *Drosophila melanogaster* and *Apis mellifera* show strong negative impacts on fecundity and survival.

**(D)** Analysis of insect family-level responses, showcasing differences across taxonomic groups such as Tachinidae, Scatopsidae, and Drosophilidae. Some families show significant effects on fecundity and development, particularly in the Coleoptera family.

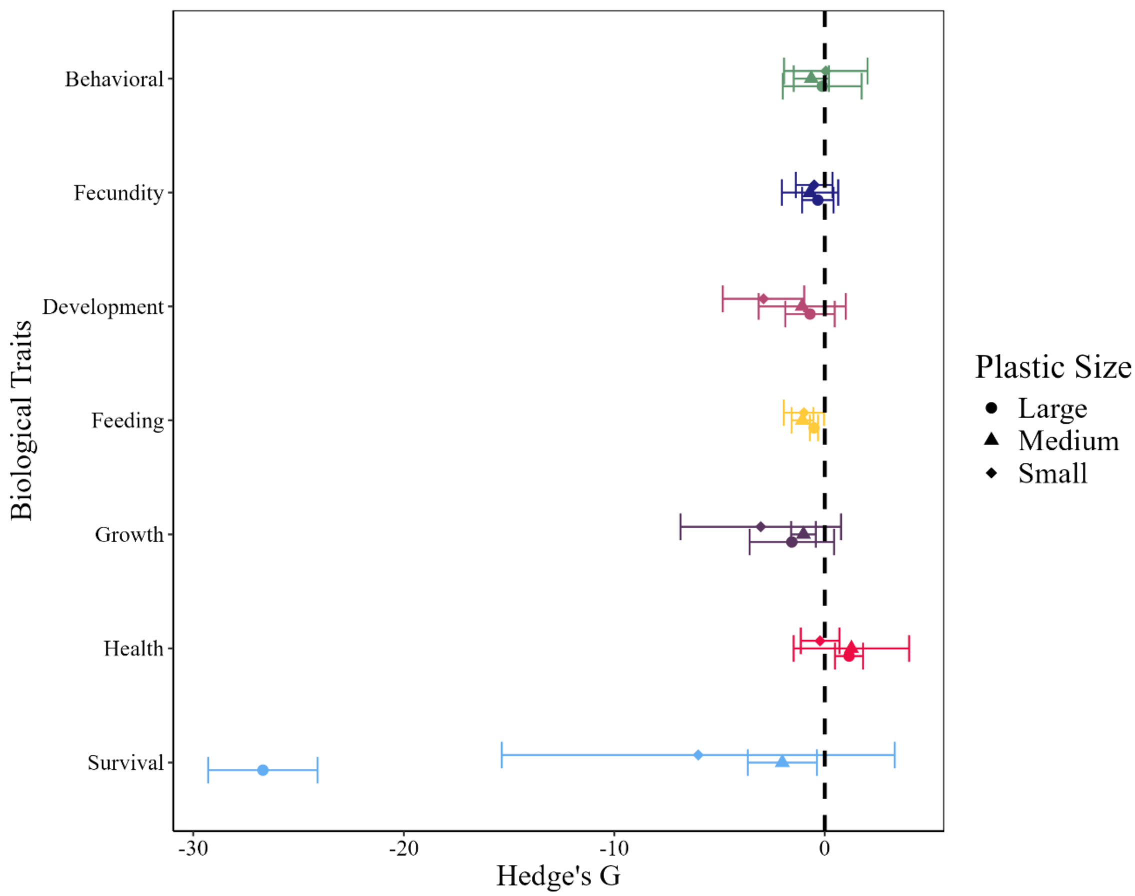
**(E)** The effects of different polymer types (e.g., PVC, PA, PET, PE) on insect traits. This analysis reveals that certain polymer types, like PVC and PE, are associated with more severe impacts, particularly on growth, health, and survival rates. Across panels, the diversity of responses across biological traits underscores the complexity of micro- and nanoplastics impacts on insect populations.

**Figure S8: Phylogenetic tree of insect species examined in a global meta-analysis on microplastics and nanoplastics impact**




This phylogenetic tree shows the evolutionary relationships between the insect species analyzed in the global meta-analysis study, “Unraveling the impact of microplastics and nanoplastics on insects”. The study investigates how various insect species, including *Apis mellifera* (honeybee), *Tenebrio molitor* (mealworm beetle), *Aedes aegypti* and *Aedes alboicutus* (mosquito), *Culex pipiens* (common house mosquito), Chironomus species (non-biting midges), *Hermertia illucens* (black solider fly), *Drosophila melanogaster* (fruit fly), and *Bombyx mori* (silkworm), are affected by microplastics and nanoplastics. The tree highlights their evolutionary divergence, helping to interpret the variation in physiological and ecological responses to plastic pollution observed across different species in the meta-analysis. This comparative approach enhances understanding of how plastic contaminations may differentially impact species based on their evolutionary history.

**Figure S9: Comparative Impact of Plastic Size on Biological Traits of Insects**




This supplementary figure presents the Hedges' G effect sizes for various biological traits of insects exposed to plastic size. The traits analyzed include behavior, development, fecundity, feeding, growth, health, and survival. The error bars represent the 95% confidence intervals, with a dashed vertical line at 0 indicating no effect. Circles represent large size, triangles signify medium, and squares denote small size of plastic. The figure highlights the differential impacts of plastic types on specific traits, with survival and health exhibiting pronounced effects under exposure to nanoplastics. These findings enhance understanding of how plastic size influences biological responses.