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Box 1 Conservation Implications of Monarch Genomics and Metabolomics

Recent advances in monarch genomics and metabolomics provide an opportunity to move beyond abundance-based conservation toward strategies that preserve functional, adaptive capacity across the migratory range.

1. Cheically informed habitat restoration. Milkweed species and populations differ substantially in cardenolide composition, inducibility, and secondary metabolite diversity, with direct consequences for monarch survival, chemical defense, and resistance to the protozoan parasite *Ophryocystis elektroscirrha* (OE) (de Roode et al., 2008; Agrawal et al., 2012; Petschenka and Agrawal, 2015). Metabolomic screening of milkweeds used in restoration projects could identify plant chemotypes that optimize larval performance while enhancing parasite resistance and predator deterrence, avoiding one-size-fits-all planting strategies.

2. Preserving adaptive genetic variation for migration. Population genomic studies indicate that migration, diapause, lipid storage, and navigation are polygenic traits shaped by subtle allele-frequency shifts across many loci (Zhan et al., 2014; Freedman and Kronforst, 2023). Conservation actions that maintain connectivity among breeding, migratory, and overwintering regions are therefore essential to preserve adaptive alleles associated with circadian timing, endocrine regulation, and metabolic endurance.

3. Metaolites as early-warning indicators. Metabolomic profiles-such as cardenolide sequestration patterns, lipid reserves, and stress-response metabolites-may provide sensitive indicators of physiological condition and migratory readiness before population declines are detectable through census data alone (Semmens et al., 2016; Thogmartin et al., 2017). Integrating metabolomic monitoring into long-term surveys could improve detection of sublethal stress caused by climate extremes, pesticide exposure, or host-plant mismatch.

4. Integrating host–parasite–microbiome dynamics. Chemical defense, parasite resistance, and gut microbiome composition interact to shape monarch fitness. Restoration strategies that consider host-plant chemistry alongside disease pressure and microbial interactions may reduce parasite prevalence and improve survival during migration and overwintering (de Roode et al., 2008; Hammer et al., 2014).

5. From molecular insight to management practice. By integrating causal genomics, pan-genomics, regulatory neurogenomics, and metabolomics, conservation efforts can prioritize not only habitat quantity but also genetic, chemical, and physiological quality. Such mechanistically informed strategies are likely to be more robust to environmental change, supporting long-term persistence of migratory monarch populations in an increasingly variable landscape (U.S. Fish and Wildlife Service, 2020; Erickson et al., 2023).

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