Poeciliid Research

The fast-X effect and Y chromosome degeneration in poeciliid fish: Insights into sex chromosome evolution

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Abstract. This news and views article critically examines recent research on the Fast-X effect and Y chromosome degeneration in poeciliid fish, focusing on their implications for sex chromosome evolution. The reviewed study highlights significant differences in the evolutionary dynamics of sex chromosomes among species, with pronounced Fast-X effects in *Poecilia picta* Regan, 1913 and *Poecilia parae* Eigenmann, 1894, where Y chromosome degeneration exposes X-linked genes to stronger selective pressures. Conversely, in species with homomorphic sex chromosomes, such as *Poecilia reticulata* Peters, 1859 and *Poecilia wingei* Poeser, Kempkes & Isbrücker, 2005, limited Y degeneration results in weaker Fast-X effects. The article explores the role of hemizygosity and dosage compensation in accelerating X chromosome evolution and underscores how varying evolutionary pressures shape sex-linked genomic patterns. These findings contribute to broader discussions on the trade-offs and evolutionary pathways associated with sex chromosome systems in vertebrates.

Key Words: Fast-X effect, Poeciliidae, hemizygosity, dosage compensation, X-linked selection, *Poecilia picta, Poecilia parae*, genetic evolution, sexual dimorphism, evolutionary genomics.

The aim of this news and views article is to critically evaluate and contextualize the findings of recent research on the Fast-X effect and Y chromosome degeneration in poeciliid fish, highlighting its broader implications for understanding sex chromosome evolution, the role of hemizygosity, and how evolutionary pressures drive variability in sex-linked genomic patterns across closely related species.

A recent study titled "Sex chromosome heteromorphism and the fast-X effect in poeciliids" was conducted by Iulia Darolti, Lydia J. M. Fong, Benjamin A. Sandkam, David C. H. Metzger, and Judith E. Mank. These researchers are affiliated with institutions such as the University of British Columbia, the University of Lausanne, and Cornell University, bringing together expertise in zoology, genetics, and evolutionary biology (Darolti et al 2023). Their investigation focused on the evolutionary dynamics of sex chromosomes in poeciliid fish, specifically exploring the Fast-X effect—a phenomenon where the X chromosome evolves faster than autosomes under certain conditions (Petrescu-Mag & Proorocu 2022; Darolti et al 2023).

The primary aim of the study was to understand how the Fast-X effect emerges during sex chromosome differentiation and the role of hemizygosity (having a single copy of the X chromosome in males) in driving this phenomenon (Darolti et al 2023). The team also sought to determine whether this effect appears early in the evolutionary divergence of sex chromosomes or only after significant degeneration of the Y chromosome. To achieve this, Darolti et al (2023) analyzed a range of poeciliid species, including the common guppy (*Poecilia reticulata*), Endler's guppy (*P. wingei*), the swamp guppy (*P. picta*), and the pentamorphic fish (*P. parae*). These species exhibit varying levels of sex chromosome differentiation, providing a gradient to study how evolutionary processes impact sex chromosomes (Oroian et al 2019; Darolti et al 2023).

Darolti et al (2023) conducted genomic analyses to assess sequence divergence and polymorphism data across the X chromosome and autosomes. They examined how differences in Y chromosome degeneration and dosage compensation (mechanisms balancing gene expression between sex chromosomes) influenced the rate of evolution on the X chromosome. Their comparative approach also included testing hypotheses about the time of origin of sex chromosomes in this clade (Darolti et al 2023).

The findings of Darolti et al (2023) revealed a remarkable variation in sex chromosome evolution among poeciliids. In species like *P. picta* and *P. parae*, where the Y chromosome is highly degenerated (see also Nanda et al 2022) and most of the X chromosome is hemizygous in males, the researchers observed a strong Fast-X effect (Darolti et al 2023). This was evidenced by significantly higher rates of nonsynonymous substitutions (changes in the protein-coding regions of genes) on the X chromosome compared to autosomes. In contrast, species like *P. reticulata* and *P. wingei*, which have largely homomorphic (similar in structure) sex chromosomes and limited Y chromosome degeneration (Petrescu-Mag 2007), showed little to no evidence of the Fast-X effect (Darolti et al 2023).

A key observation was the role of hemizygosity in amplifying the Fast-X effect. In *P. picta* and *P. parae*, the complete loss of functional Y chromosome genes exposed X-linked genes to selection in males, leading to stronger purifying selection against harmful mutations and positive selection for beneficial ones (Darolti et al 2023) (Figure 1). Moreover, these species exhibited chromosome-wide dosage compensation, which further enhanced the Fast-X effect by maintaining balanced gene expression between the sexes (Darolti et al 2023). In species with homomorphic sex chromosomes, the lack of significant Y degeneration and incomplete recombination suppression between the X and Y chromosomes likely prevented the accumulation of mutations on the X chromosome (Darolti et al 2023; see also how this was predicted by Charlesworth 1978; Rice 1987ab; Brooks 2000; Lindholm & Breden 2002).

The study's findings have broad implications for understanding sex chromosome evolution. First, it highlights the importance of hemizygosity and dosage compensation in driving rapid evolutionary changes on the X chromosome. Second, the results suggest that the Fast-X effect is not an inherent feature of sex chromosome systems but depends on the degree of Y chromosome degeneration and the evolutionary pressures acting on the X chromosome. Finally, the study provides evidence for a relatively recent origin of the poeciliid sex chromosome system, with significant Y chromosome degeneration occurring only in the immediate ancestors of *P. picta* and *P. parae*.

These discoveries shed light on the evolutionary mechanisms shaping sex chromosomes and underscore the variability in how different species navigate the trade-offs associated with sex-linked inheritance. By investigating poeciliid fish, the researchers have contributed valuable insights into the broader dynamics of genome evolution, particularly in the context of sex chromosomes, which play a critical role in sexual dimorphism and reproductive biology.

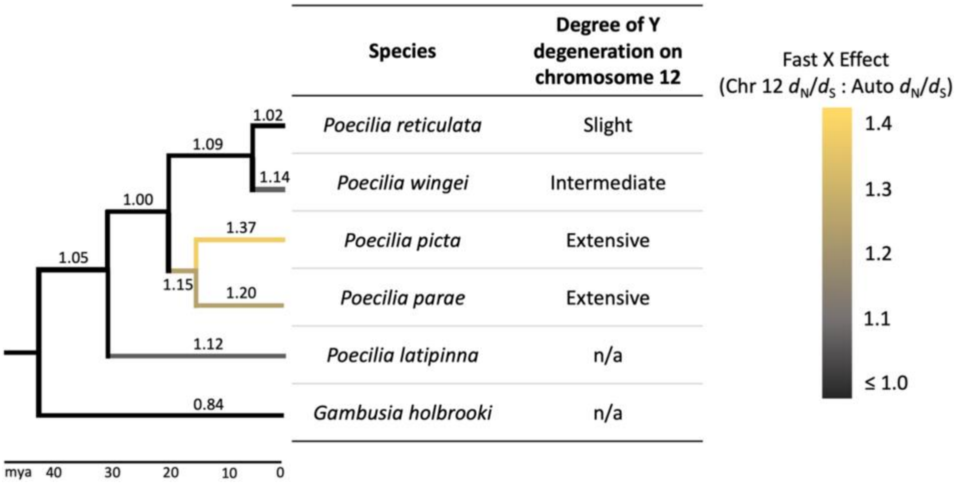

Figure 1. Fast-X effect, calculated as the ratio of dN/dS for the X chromosome (excluding the PAR) to that of the autosomes, across the poeciliids. In *Poecilia latipinna* and *Gambusia holbrooki*, chromosome 12 has not been implicated as the sex chromosome. Numbers on each branch represent the estimated Fast-X effect. Phylogeny by Darolti et al (2023), based on Meredith et al (2010) and Rabosky et al (2018). PAR stands for pseudoautosomal region. The notation dN/dS refers to the ratio of nonsynonymous (dN) to synonymous (dS) substitution rates in coding sequences. This ratio is used as a measure of the selective pressure acting on protein-coding genes: A dN/dS ratio < 1 suggests purifying selection, where harmful mutations are being removed; a dN/dS ratio = 1 indicates neutral evolution, where mutations are neither beneficial nor harmful; a dN/dS ratio > 1 implies positive selection, where advantageous mutations are being favored. dN/dS ratio is used to compare the rates of evolution of X-linked genes versus autosomal genes and assess the presence of the Fast-X effect, particularly in species with highly differentiated sex chromosomes.

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