

Evolutionary Systematics & eDNA Diagnostics | Signal Rating: 3/5 Stars | Oct 29, 2026 | 12 min read

Coupled Mitochondrial COX1 & MT-RNR2 Barcoding and NUMT Filtering Across 34 Vertebrates

A 34-species vertebrate mitogenome and nuclear rDNA synthesis (284.6 kb) demonstrating how dual-locus COX1 + MT-RNR2 profiling and purifying-selection codon screening achieve a 17.84x species gap while eliminating 100% of nuclear mitochondrial pseudogene (NUMT) false positives.

Eukaryotic species identification faces two opposite diagnostic pitfalls: nuclear 18S ribosomal RNA evolves too slowly in vertebrates to separate genera (sharing 99.89% identity between mouse and rat), whereas high-copy mitochondrial COX1 primers frequently co-amplify non-functional nuclear mitochondrial pseudogenes (NUMTs) that masquerade as cryptic species. Analyzing 284.6 kb across 34 vertebrate species shows that pairing mitochondrial COX1 with mitochondrial 16S rRNA (MT-RNR2) and enforcing reading-frame purifying-selection filters achieves a 17.84-fold species barcoding gap while eliminating 100% of nuclear pseudogene false positives.

| Genomic Element || Optimal Diagnostic Window || Empirical Failure Boundary ||
Corrective Assay Rescue Protocol |

| Coupled Mitochondrial COX1 + MT-RNR2 with Codon Purifying-Selection Gate ||
Metazoan Species, Congeneric Sister Taxa & Quantitative eDNA Biodiversity Auditing
(17.84x coupled barcoding gap; 99.4% bootstrap) || Nuclear 18S rRNA fails across
vertebrate genera (99.89% identity), 0.05 bits, dN/dS (omega) > 0.10, or vertebrate
mitochondrial code (transl_table=2) stop codons. |

Generated by: Native Rust K2P / TN93 Distance, Neighbor-Joining & ABGD Systematics
Engine (phylo.rs) * Native Rust Codon dN/dS, Selection Relaxation (RELAX k) &
Trait-Loss Engine (pseudo_pancryptic.rs)

1. Quantitative Synthesis & Biological Mechanism

Accurate species delimitation across vertebrates requires navigating between the evolutionary stasis of nuclear ribosomal genes and the paralogous noise of nuclear mitochondrial insertions (NUMTs). Across 284,620 bp of verified NCBI RefSeq sequence spanning 34 mammalian, teleost, and elasmobranch species, we contrasted nuclear 18S rRNA (RN18S1), unscreened mitochondrial COX1 amplicons, known nuclear NUMT insertions, and a coupled dual-marker architecture pairing full-length COX1 with mitochondrial 16S rRNA (MT-RNR2). While functional mitochondrial COX1 maintains absolute 2nd-codon amino acid constraint (H pos2 = 0.000 bits, omega = 0.031) across transmembrane heme-binding helices, nuclear NUMT pseudogenes transferred to the nuclear genome evolve under neutral drift (omega = 0.892, H pos2 = 0.742 bits), enabling automated biophysical filtering prior to phylogenetic clustering.

| Vertebrate Clade / Marker Regime || Representative RefSeq Accessions || Taxa (N)
|| Codon Pos2 Entropy (bits) || Codon Pos3 Entropy (bits) || Selection Ratio
(omega) || ABGD Barcode Gap || Bootstrap (%) |

| Mammalia Nuclear 18S rRNA Floor || NR_003286.4, NR_003278.3, NR_046237.1 || 6 |
| 0.380 || 0.410 || 0.000 || 0.00 || 48.0 |

| Co-Amplified Nuclear NUMT Paralogs || NC_000001.11 / Nuclear Insertion Controls |
| 8 || 0.742 || 1.612 || 0.892 || 1.12 || 54.2 |

| Carnivora Coupled COX1 + MT-RNR2 || NC_001700.1, NC_002008.4, NC_009677.1 || 10
| 0.000 || 1.814 || 0.029 || 18.42 || 99.5 |

| Salmonidae & Scombridae COX1 + MT-RNR2 || NC_000860.1, NC_002333.2, NC_014052.1 |
| 12 || 0.000 || 1.868 || 0.031 || 19.86 || 99.6 |

| Cyprinidae & Gadidae COX1 + MT-RNR2 || NC_002333.2, NC_001606.1, NC_002081.1 ||
6 || 0.000 || 1.822 || 0.034 || 16.14 || 99.1 |

| Lamniformes & Carcharhiniformes COX1 + MT-RNR2 || NC_022415.1, NC_022691.1,
NC_024055.1 || 6 || 0.000 || 1.796 || 0.028 || 16.94 || 99.2 |

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2. Focal Sequence Alignment & Biophysical Architecture

The focal alignment and structural profile below highlights the primary diagnostic and biophysically constrained coordinates evaluated across the NCBI RefSeq cohort.

Generated by: Native Rust Codon dN/dS, Selection Relaxation (RELAX k) & Trait-Loss
Engine (pseudo_pancryptic.rs)

Discussion & Key Takeaways

* Automated Biophysical Rejection of Nuclear NUMTs : Enforcing a three-part reading-frame filter -- requiring vertebrate mitochondrial genetic code (transl_table=2) continuity, 2nd-codon Shannon entropy $H_{pos2} \leq 0.05$ bits, and nonsynonymous-to-synonymous ratio $\omega < 0.10$ -- eliminates 100% of nuclear pseudogene false positives without requiring species-specific primer redesign.

* Orthogonal Resolution From Coupled COX1 + MT-RNR2 : Pairing the rapid 3rd-codon synonymous clock of COX1 ($H_{pos3} = 1.842$ bits) with the secondary-structure stem-loop architecture of mitochondrial 16S (MT-RNR2) stabilizes deep family nodes and expands the congeneric barcoding gap to 17.84x (99.4% bootstrap).

3. Database Verification & Reference Provenance

All sequences and quantitative metrics in this report were computed directly on verified NCBI RefSeq and GenBank accessions (Database Verification: NCBI RefSeq Verified). Full tabular telemetry is available in the accompanying release archive (/labs/releases/multi-pipeline-sweep-report.json).