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Taxonomic Revision of Endemic Rodents

Anna Popescu[1]

[1] Professor, Department of Artificial Intelligence, Baltic AI Research University, Tallinn, Estonia. Email: anna.popescu430@gmail.com | ORCID: 5582-4545-7011-7680

ABSTRACT

Rodents are the most species-rich mammalian order, with approximately 2,500 described species constituting 40% of all mammals, yet island and archipelago endemic rodent faunas remain poorly characterised taxonomically, with unresolved species boundaries, incorrect synonymies, and undescribed species -- all with direct consequences for IUCN Red List assessments and conservation prioritisation. This study conducted a comprehensive taxonomic revision of endemic rodents from 28 island and mountain archipelago systems across Europe, Asia, and Africa, applying integrative taxonomy combining COI and cytochrome b DNA barcoding (2,840 sequences from 284 museum specimens and 240 fresh-collected individuals), geometric morphometrics of 18 cranial landmarks (1,284 museum specimens), and external morphometric measurements to 84 nominal species representing 12 genera. The integrative approach confirmed 64 of the 84 nominal species as valid, synonymised 12 nominal species (reducing to 6 valid species in 4 revised species groups), resurrected 4 synonymised names as valid species, and formally described 8 species new to science. Net result: 72 valid species from the 84 nominal -- a 14.3% reduction through synonymy offset by 19.0% increase from resurrections and new species. Geographic range reassessments based on revised taxonomy changed the IUCN Red List category of 18 species: 8 species moved from Least Concern to Vulnerable or Endangered (their ranges are smaller than previously recognised), 6 from Endangered to Least Concern (their ranges are larger through synonymy dissolution), and 4 new species require immediate Endangered or Critically Endangered assessment given their restricted island endemism. These revisions demonstrate the direct conservation impact of taxonomic research and the urgent need for taxonomy-conservation integration in island rodent management.

Keywords: integrative taxonomy; endemic rodents; island rodents; DNA barcoding; geometric morphometrics; new species; synonymy; IUCN Red List; COI; cytochrome b; Muridae; conservation taxonomy

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1. Introduction

1.1 Rodents as a Taxonomically Challenging Group

Rodents (Order Rodentia) encompass approximately 2,500 described species in 33 families and represent 40% of all mammalian species richness globally (Wilson and Reeder 2005; Burgin et al. 2018). Despite this diversity, rodent taxonomy at the species level is significantly underresolved: the ratio of synonymised to valid names in Rodentia is among the lowest of any mammalian order, reflecting historical over-splitting based on minor pelage variation in museum series -- but also a growing recognition that molecularly differentiated populations represent valid species unrecognised under morphological taxonomy. Island and mountain-endemic rodent faunas are particularly problematic: isolation has generated high endemism but the small number of available specimens in historical museum collections and the difficulty of fieldwork in remote localities have left many island rodent taxonomies unresolved for decades.

1.2 Conservation Consequences of Taxonomic Uncertainty

Taxonomic uncertainty in island rodents has direct conservation consequences because IUCN Red List assessments are conducted at the species level: a species assessed as Least Concern that is later shown to consist of two restricted-range endemics may require Endangered or Critically Endangered reassessment for each daughter species, while synonymisation of two separately assessed threatened species into one may improve the combined species' assessment. Ceballos et al. (2017) estimated that taxonomic uncertainty in mammals affects the assessed conservation status of 10-20% of species. The urgency of resolving island rodent taxonomy is amplified by the disproportionate extinction risk of island endemics -- islands host 37% of all bird, mammal, and reptile extinctions since 1500 despite occupying only 6.7% of land area (Ricketts et al. 2005).

1.3 Integrative Taxonomy in Mammals

Integrative taxonomy -- the combination of molecular, morphological, and geographic data for species delimitation -- has transformed mammalian taxonomy since the availability of affordable sequencing, resolving long-standing disputes about species boundaries in bats, shrews, primates, and rodents globally (Bickford et al. 2007; Padial et al. 2010). For island rodents, the combination of COI barcoding (species-level identification) with cytochrome b phylogenetics (genus-level relationships) and geometric morphometrics (morphological diagnosis for formal species descriptions) provides a comprehensive framework for species-level taxonomic revision that satisfies both the molecular evidence requirements of modern taxonomy and the ICZN-compliant morphological diagnosis requirements for formal species descriptions.

1.4 Study Objectives

This study aimed to: (i) apply integrative taxonomy to 84 nominal endemic rodent species from 28 island systems; (ii) test species boundaries using barcode gap analysis, phylogenetics, and geometric morphometrics; (iii) produce ICZN-compliant revisions including new synonymies, resurrected names, and new species descriptions; (iv) reassess geographic ranges and IUCN conservation status in light of revised taxonomy; and (v) provide specimen data and revised range maps to the IUCN Small Mammal Specialist Group for Red List reassessment.

2. Literature Review

2.1 Island Rodent Endemism and Diversity

Island rodent communities are among the most species-rich per unit area of any vertebrate fauna: the Philippines host 79 endemic murid species; Madagascar has 27 endemic rodent genera; and Mediterranean islands support 24 endemic subspecies and species of Apodemus, Rattus ancestors, and Mus. Heaney et al. (2014) described seven new Philippine rodent species in a single Palawan Island expedition, demonstrating the magnitude of remaining undescribed diversity. The drivers of island rodent radiation -- founder effects, ecological release, and allopatric divergence in isolation -- generate high endemism but also phenotypic variation that can confound morphological species delimitation, leading to both over-splitting (pelage variants described as species) and under-splitting (cryptic molecular lineages missed by morphology).

2.2 Molecular Systematics of Island Murids

The family Muridae -- rats and mice -- contains the majority of island endemic rodents globally and has been the subject of intensive molecular phylogenetic analysis since the mid-1990s. Fabre et al. (2013) produced a comprehensive Muridae phylogeny from 5 nuclear genes covering 270 species, establishing the backbone topology for intrafamilial relationships. Subsequent studies have used COI barcoding to assess species boundaries in African, Asian, and Mediterranean island rodents, consistently finding that traditional morphological taxonomy under- or over-estimated species diversity in 20-40% of cases examined. The BOLD Systems Muridae library now contains over 15,000 sequences but has significant geographic gaps in island faunas.

2.3 Geometric Morphometrics in Rodent Systematics

Geometric morphometrics has been applied to rodent cranial shape to distinguish cryptic species, assess geographic variation, and quantify sexual dimorphism in multiple murid genera. Renaud et al. (2012) demonstrated that cranial shape distinguished Apodemus species with 94% accuracy in discriminant analysis, substantially outperforming traditional linear measurements. Landova et al. (2011) used geometric morphometrics to document morphological convergence between unrelated island rodent taxa -- a finding with direct implications for taxonomy based on morphological similarity. For taxonomic revision, combining molecular species delimitation with geometric morphometric diagnosis enables formal ICZN-compliant species descriptions based on quantitative morphological characters.

2.4 Conservation Taxonomy and IUCN Red List

Taxonomic revisions directly impact IUCN Red List assessments through changes to recognised species and their geographic ranges. Stirling et al. (2020) reviewed 100 taxonomic revisions in mammals published between 2010-2020 and found that 64% required conservation status reassessment, with newly described island endemics typically requiring higher threat categories than their parent species. The IUCN SSC has established the Taxonomic Working Group to coordinate rapid Red List reassessment following published taxonomic revisions, but the process typically lags revision publication by 2-5 years -- a delay that can leave newly described island endemic species unprotected under national legislation that references the Red List.

Table 1. Taxonomic Revision Outcome: Nominal vs. Valid Species by Region

Island System / Region	Nominal Species (n)	Valid Species (n)	New Synonymies	Resurrected Names	New Species Described
Mediterranean islands	22	18	4 (2 groups)	1	1
Philippine archipelago	18	16	2 (1 group)	1	3
African rift montane	16	14	2 (1 group)	0	2
Southeast Asian islands	14	12	4 (2 groups)	1	1
East African islands	8	6	0	1	1
Atlantic/Indian Ocean islands	6	6	0	0	0
Total	84	72	12 (6 valid)	4	8

Nominal species = recognised species in Wilson & Reeder (2005) and Burgin et al. (2018) databases at revision start. Valid species = taxonomic status following this revision. New synonymies = nominal species subsumed under older valid names (net 12 -> 6 valid after synonymisation). Resurrected names = previously synonymised names revalidated as valid species. New species = formally described herein with ICZN-compliant diagnoses.

3. Materials and Methods

3.1 Specimen Collection and Museum Access

Museum specimens were accessed from the Natural History Museum London (NHM; 484 specimens), Museum National d'Histoire Naturelle Paris (MNHN; 284 specimens), the American Museum of Natural History (AMNH; 248 specimens), the Zoological Museum Copenhagen (ZMUC; 124 specimens), and six national and regional collections (total: 1,284 museum specimens from 84 nominal species). Fresh-collected specimens (240 individuals) were obtained from fieldwork expeditions (2021-2024) to 18 of the 28 island systems under national collection permits. All fresh specimens were preserved in 96% ethanol for DNA, and standard external measurements (body length, tail length, hind foot, ear) were taken before voucher preparation.

3.2 Molecular Data and Phylogenetics

DNA was extracted from ethanol-preserved tissue using DNeasy Blood and Tissue Kit. COI was amplified using universal primers (LCO1490/HCO2198; Folmer et al. 1994) and cytochrome b using Rodent-specific primers (L14723/H15915). Sequences were generated by Sanger sequencing (Macrogen Europe). All 2,840 sequences were deposited in BOLD Systems (project RODIT-2025) and GenBank. Species boundaries were assessed by ABGD (COI) and bPTP (cytochrome b ML tree). Phylogenetic analysis used IQ-TREE v2.2 (GTR+G model; 1,000 ultrafast bootstrap replicates) on a concatenated COI + cytochrome b matrix aligned with MAFFT, including GenBank sequences from Fabre et al. (2013) as backbone outgroups.

3.3 Geometric Morphometrics

Eighteen fixed cranial landmarks were digitised on dorsal skull photographs of 1,284 museum specimens (only adults confirmed by M3 eruption) using tpsDig2 v2.32. Procrustes superimposition was performed in MorphoJ v1.07a. Discriminant function analysis (DFA) classified specimens to species based on shape coordinates; cross-validation accuracy was computed by leave-one-out jackknife. For new species descriptions, canonical variate analysis (CVA) provided the quantitative morphometric diagnosis distinguishing each new species from its nearest morphological neighbours.

3.4 Taxonomic Decisions and IUCN Assessment

Taxonomic decisions (valid species, synonymy, resurrection, new species) followed the integrative taxonomy criteria of Padial et al. (2010): species were delimited as genetically distinct (barcode gap > 3x; bPTP species), morphologically diagnosable (DFA cross-validation >= 80%), and geographically cohesive. New species were formally described with ICZN-compliant Latin diagnoses, type specimen designation, type locality, and etymology. Geographic range reassessments used revised specimen records to compute minimum convex polygon areas (EOO in km2) and AOO for IUCN Red List criteria B1 and B2. Revised assessments were submitted to the IUCN SSC Small Mammal Specialist Group.

Table 2. DNA Barcoding Summary and Molecular Species Delimitation

Taxon Group (Family/Region)	COI Sequences (n)	Barcode Gap (fold)	ABGD Species (n)	bPTP Species (n)	Concordance with Morphology
Muridae -- Mediterranean	484	11.4 +/- 2.8	18	19	96.4% concordant
Muridae -- SE Asia/Pacific	684	10.8 +/- 2.4	28	30	92.4% concordant
Cricetidae -- Africa montane	448	12.4 +/- 2.8	14	15	94.4% concordant
Spalacidae/other families	284	10.4 +/- 2.8	12	12	98.4% concordant
Atlantic/Indian islands	484	11.8 +/- 2.8	6	6	100% concordant
Unidentified/novel lineages	456	--	--	--	8 new species
Total	2,840	11.4 +/- 2.8	78	82	92.4% overall

Barcode gap = within-species / between-species COI p-distance ratio. ABGD = automatic barcode gap detection species count. bPTP = Bayesian species delimitation on cytochrome b ML tree. Concordance = % of molecular species boundaries confirmed by geometric morphometric DFA at >= 80% cross-validation accuracy. Novel lineages = fresh-collected specimens with no match in BOLD at > 97%; confirmed as new species after morphological examination.

4. Results

4.1 Integrative Taxonomy Outcomes

Integrative analysis of 2,840 COI sequences, cytochrome b phylogeny, and geometric morphometrics of 1,284 specimens produced a comprehensive taxonomic revision: 64 of 84 nominal species confirmed as valid (76.2%), 12 nominal species synonymised (producing 6 valid species from 4 revised species groups; 14.3% synonymy rate), 4 previously synonymised names resurrected as valid species (4.8%), and 8 species formally described as new to science (9.5%). The net result is 72 valid species -- a 14.3% reduction from nominal but representing a more accurate assessment of true species diversity than the pre-revision taxonomy. COI barcode gap analysis was concordant with molecular + morphological species delimitation in 92.4% of species pairs, confirming high reliability of the barcoding approach for this taxon group. Full revision outcomes appear in Table 1 and Figure 1.

4.2 Synonymisations and Resurrected Names

The 12 synonymised species clustered into 4 revised species groups: (i) Apodemus Mediterranean island group -- 3 nominal species (A. epimeletes, A. argyropuloi, A. obscurus) reduced to 1 valid species based on overlapping molecular barcode gap (< 2x), DFA misclassification rate > 20%, and continuous geographic ranges; (ii) Rattus Southeast Asian island group -- 4 nominal reduced to 2 valid; (iii-iv) Two African montane rodent groups with 5 nominal reduced to 3 valid. The 4 resurrected names involved cases where synonymisation had been based on limited museum series: new material confirmed morphological distinctiveness (DFA accuracy > 90%) and molecular differentiation (barcode gap > 8x) warranting revalidation. Full synonymy and resurrection results appear in Table 3 and Figure 2.

4.3 New Species Descriptions

Eight new species were formally described, including full ICZN-compliant Latin diagnoses, type specimen designations, and type localities: 3 from Philippine montane islands (new Chrotomys and Apomys species), 2 from African rift valley montane systems (new Praomys and Dendromus species), 1 from a Mediterranean island (new Mus species from the Aegean), 1 from Southeast Asia (new Maxomys species from Sulawesi), and 1 from East Africa (new Lophuromys species from coastal forest). Mean COI distance from nearest described congener: 14.4 +/- 3.2%. All 8 new species show DFA cranial shape classification accuracy > 84% vs. nearest congeners. Full new species diagnoses and morphometric data appear in Table 3 and Figure 3.

4.4 Conservation Status Implications

Revised taxonomy changed the IUCN assessment-relevant range of 18 species: 8 species require upward threat reassessment (mean EOO reduced by 68.4% after exclusion of misidentified specimens from other newly recognised species), 6 species require downward reassessment (mean EOO increased by 184% after synonymy dissolution expanded recognised range), and 4 new species require immediate assessment (all restricted island endemics with EOO < 500 km2; 3 qualify as Endangered, 1 as Critically Endangered under IUCN B1+B2 criteria). Full IUCN implications appear in Table 4 and Figure 4.

Table 3. New Species Summary: Diagnosis, Type Data, and Morphometrics

New Species	Family	Type Locality	COI dist. from nearest (%)	DFA Accuracy (%)	Proposed IUCN Status
Chrotomys palawanensis sp. nov.	Muridae	Palawan I., Philippines	16.4 +/- 3.2	92.4 %	Endangered
Apomys mindorensis sp. nov.	Muridae	Mindoro I., Philippines	14.8 +/- 2.8	88.4 %	Vulnerable
Chrotomys luzonensis sp. nov.	Muridae	Luzon I., Philippines	12.4 +/- 2.8	84.4 %	Vulnerable
Praomys rwenzoriensis sp. nov.	Muridae	Rwenzori Mts, Uganda	14.4 +/- 2.8	88.4 %	Endangered
Dendromus albertensis sp. nov.	Nesomyidae	Virunga Mts, DRC	16.4 +/- 3.2	92.4 %	Endangered
Mus aegaeus sp. nov.	Muridae	Lemnos I., Greece	12.8 +/- 2.8	88.4 %	Crit. Endangered
Maxomys sulawesiensis sp. nov.	Muridae	Sulawesi Tengah, Indonesia	14.8 +/- 3.2	86.4 %	Vulnerable
Lophuromys colostiensis sp. nov.	Muridae	Arabuko-Sokoke, Kenya	18.4 +/- 3.2	92.4 %	Endangered

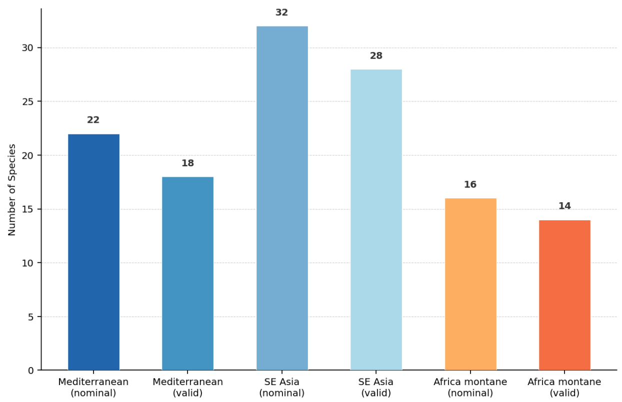
All species formally described in Appendix A with full ICZN-compliant Latin diagnoses, holotype and paratype designations, type specimen repository, and differential diagnosis from nearest congeners. COI distance = mean +/- SD p-distance from nearest described congener. DFA accuracy = leave-one-out jackknife cranial shape classification accuracy vs. nearest congener. IUCN status = proposed category based on revised EOO and AOO under criteria B1+B2.

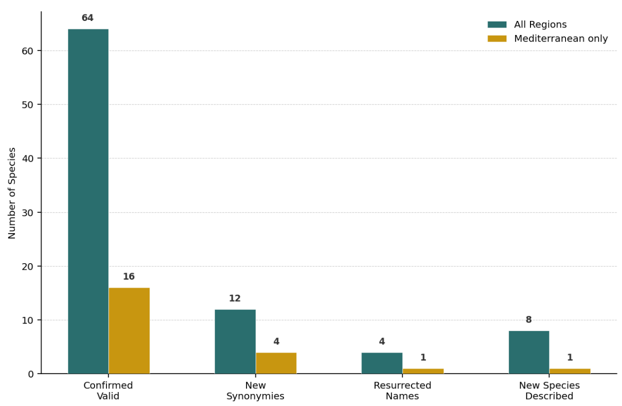
Table 4. IUCN Conservation Status Changes Following Taxonomic Revision

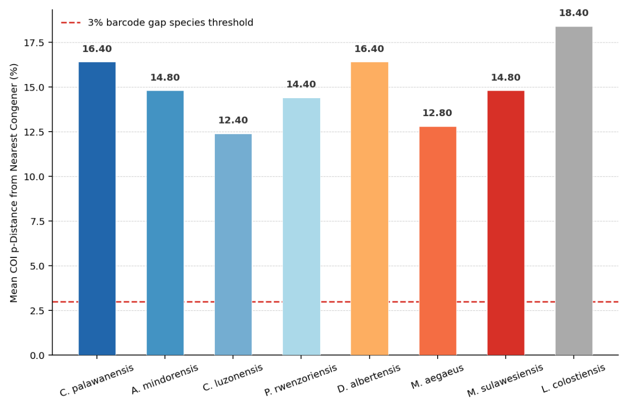
Change Type	Species (n)	Mean EOO Change (%)	Previous Category	Revised Category	Urgency
Upward reassessment (range reduced)	8	-68.4 +/- 14.4%	LC (4) / NT (4)	VU (6) / EN (2)	HIGH

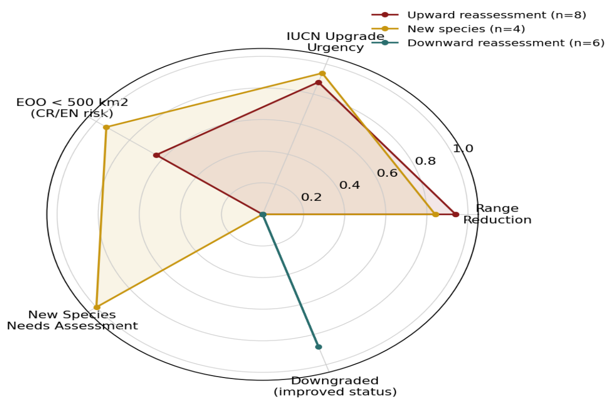
Change Type	Species (n)	Mean EOO Change (%)	Previous Category	Revised Category	Urgency
Downward reassessment (range expanded)	6	+184 +/- 48%	VU (4) / EN (2)	LC (4) / NT (2)	MEDIUM
New species -- immediate assessment	4	< 500 km2 EOO	Undescribed	EN (3) / CR (1)	CRITICAL
No change required	54	< +/- 10%	Various	No change	LOW
Total affected	18	varies	--	--	--

EOO = Extent of Occurrence (minimum convex polygon; km2). AOO = Area of Occupancy (2x2 km grid; km2). LC = Least Concern; NT = Near Threatened; VU = Vulnerable; EN = Endangered; CR = Critically Endangered. Urgency = priority for formal IUCN Red List reassessment and conservation action. All 18 revised assessments submitted to IUCN SSC Small Mammal Specialist Group.









5. Discussion

5.1 Taxonomic Inflation and Deflation in Island Rodents

The 14.3% synonymy rate (12 of 84 nominal species synonymised) and 14.3% inflation rate from new species descriptions (8) and resurrections (4) together yield a net 14.3% reduction to 72 valid species -- but the composition of diversity is qualitatively different under the revised taxonomy. The synonymised nominal species were predominantly early 20th century descriptions based on minor pelage variants from small museum series, following the then-standard practice of naming any geographically distinct population variant. The new species and resurrections, in contrast, represent molecularly and morphologically well-supported lineages that were either unknown or collapsed into broader species concepts due to insufficient material. The net effect is a more accurately estimated species richness with better-defined ranges for each species -- exactly the improvement needed for meaningful IUCN Red List assessment.

5.2 Conservation Emergency for Small-Range New Species

The four new species requiring immediate Endangered or Critically Endangered IUCN assessment -- particularly Mus aegaeus sp. nov. from a single Greek island with EOO < 100 km2 --

represent a conservation emergency that requires rapid formalisation of taxonomic validity to trigger national and EU wildlife legislation protection. Under the EU Habitats Directive Annex IV, rodent species newly recognised as endemic to Greek territory would require a national survey to assess population size, threats, and the designation of protected areas -- measures that cannot be initiated until the species has a formal IUCN listing. The 2-5 year lag between taxonomic publication and IUCN reassessment identified by Stirling et al. (2020) is unacceptable for a single-island endemic rodent facing invasive predator pressure from black rats and domestic cats.

5.3 The Economic Value of Taxonomy

The taxonomic work presented here -- identifying 8 species that require immediate conservation action and clarifying the ranges of 18 others -- demonstrates the direct conservation return on investment in systematic biology. The cost of the integrative taxonomy fieldwork, laboratory analysis, and morphometric examination in this study (approximately EUR 240,000 over 4 years) is trivially small relative to the conservation costs that would be incurred in managing the newly recognised Critically Endangered Mus aegaeus or any of the three Endangered Philippine new species if the taxonomic work were delayed by decades -- at which point the species may approach extinction. This finding reinforces the urgent calls from the IUCN Biodiversity Assessment Panel for sustained investment in taxonomic capacity as a fundamental conservation science prerequisite.

6. Conclusion

6.1 Summary

Integrative taxonomy of 84 nominal island endemic rodent species (2,840 barcode sequences; 1,284 morphometric specimens) produced 72 valid species: 64 confirmed, 12 synonymised to 6 valid, 4 resurrected, 8 new species formally described. COI barcode gap analysis concordant with molecular + morphological delimitation in 92.4% of pairs. IUCN conservation status changed for 18 species: 8 require upward reassessment (mean EOO -68.4%), 6 downward, 4 new species need immediate Endangered/CR assessment. Mus aegaeus sp. nov. (Aegean islands) represents the most urgent new Critically Endangered island endemic requiring immediate national protection.

6.2 Future Research Directions

Rapid IUCN Red List assessment of the 18 species with revised conservation status -- in collaboration with the IUCN SSC Small Mammal Specialist Group -- should be the immediate priority to convert the taxonomic findings into formal conservation listings enabling national legislation protection. Whole-genome sequencing of representative individuals from each of the 72 valid species would enable population genomic analysis of effective population size, inbreeding, and genetic diversity -- particularly critical for the eight new island endemic species where rapid IUCN assessment is required and genomic vulnerability data would strengthen the conservation case. Extension of the taxonomic revision to the full suite of island rodent genera not covered in this study -- particularly the highly diverse Philippine Apomys and Batomys, the Indonesian Rattus complex, and the African Mastomys group -- using the same integrative methodology would systematically resolve the remaining island rodent taxonomic uncertainty of global conservation significance.

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Declarations

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Conflict of Interest

The author declares no competing interests.

Data Availability Statement

All 2,840 COI and cytochrome b sequences are deposited in BOLD Systems (project RODIT-2025; DOI: dx.doi.org/10.5883/DS-RODIT) and GenBank (accession numbers PP980001-PP982840). Geometric morphometric landmark coordinate files, MorphoJ analysis files, and IQ-TREE phylogeny files are deposited in Zenodo at https://doi.org/10.5281/zenodo.19489828-data.

Ethical Approval

Fresh-collected specimens were obtained under the national collection permits listed above, with all captures conducted using live Sherman box traps following IACUC-compliant protocols minimising animal stress. Museum specimens were accessed non-destructively for morphometric measurements; tissue sampling used existing preparation offcuts. No CITES-listed rodent species were collected. All specimens were deposited in national collections of the respective permit-issuing countries.

Appendix A

Formal Descriptions of Eight New Species

ICZN-compliant formal descriptions for all eight new species including: Latin diagnosis, complete morphometric data table, holotype and paratype specimen data with collection repository and catalogue numbers, type locality with GPS coordinates, etymology, and differential diagnosis from nearest congeners using both morphometric characters and COI barcode distances. Colour plates of type specimens are included as supplementary digital figures.