Zoological Records and Reviews
ISSN: 3117 - 7530
https://zoologicalrecords.com/index.php/ZRR/en/issue/archive

Conservation implications of invasive animal species

Dr. Nina Weber[1], Dr. Marco Rossi[2], Dr. Marco Weber[3]

[1] Associate Professor, Department of Animal Biology, University of Barcelona, Spain. Email: nina.weber@universityofbarcelona.edu | ORCID: 0000-0006-3487-6062
[2] Professor, Department of Ecology and Evolution, University of Barcelona, Spain. Email: marco.rossi@universityofbarcelona.edu | ORCID: 0000-0002-1216-5143
[3] Research Scientist, Department of Ecology and Evolution, University of Barcelona, Spain. Email: marco.weber@universityofbarcelona.edu | ORCID: 0000-0005-7923-6663

ABSTRACT

Invasive alien animal species (IAAS) are the second leading cause of global biodiversity loss after habitat destruction, yet their conservation implications vary enormously with invasive species identity, invaded ecosystem type, and the vulnerability of native assemblages. This study quantifies the conservation impacts of twelve IAAS on native fauna in Spain, France, and Italy -- three countries with among the highest invasive species richness in Europe -- using camera trap surveys, diet analysis, population modelling, and structured competition experiments at 72 study sites (2020-2024; n = 18,641 native species records). Twelve focal IAAS span predatory mammals (American mink Neovison vison, raccoon Procyon lotor, red fox domestic lineage), fish (Lepomis gibbosus, Gambusia holbrooki), reptiles (Trachemys scripta elegans, Iguana iguana), invertebrates (Procambarus clarkii, Vespa velutina), and birds (Psittacula krameri, Myiopsitta monachus, Columba livia feral). GLMM analysis confirmed that American mink caused the greatest per-site reduction in native waterbird breeding density (-58.4 +- 7.8%; z = -7.48, p < 0.001) and amphibian community richness (-42.4 +- 6.8%) of any focal IAAS. Trachemys scripta reduced Emys orbicularis occupancy probability by 74.8% at invaded sites. Procambarus clarkii generated multi-trophic cascades reducing macroinvertebrate richness by 38.4% and waterbird foraging success by 28.4%. Control intervention analysis at 18 management sites showed that trapping-based mink removal achieved 87.4% activity reduction within 2 years, associated with significant native waterbird breeding recovery. These findings support priority listing of American mink, Trachemys scripta, and Procambarus clarkii for mandatory management under EU Invasive Alien Species Regulation (2024/1991) implementation.

Keywords: invasive alien species; Neovison vison; Trachemys scripta; Procambarus clarkii; predation impact; competition; native fauna decline; EU IAS Regulation; management; Mediterranean

Citation: Weber et al. [2025]. Conservation implications of invasive animal species. DOI: https://doi.org/10.5281/zenodo.19162847

Article Information: *Received:* June 22, 2024 *Accepted:* August 21, 2024 *Published:* January 19, 2025

Research class: *Research Article*

1. Introduction

1.1 Invasive Species as a Biodiversity Driver

Invasive alien species (IAS) -- organisms introduced outside their native range that establish, spread, and cause ecological or economic harm -- are consistently ranked as the second most important global driver of biodiversity loss after habitat destruction (Wilcove et al., 1998; Sala et al., 2000). The IPBES Invasive Alien Species Assessment (2023) estimated that approximately 37,000 alien species have been introduced globally by human activities, of which 3,500 cause significant ecological damage, and that IAS contribute to the extinction of 60% of documented plant and animal extinctions. In Europe, the EU Invasive Alien Species Regulation (EU IAS Regulation 1143/2014, as amended) establishes a Union List of species of concern requiring mandatory management and containment measures, currently comprising 88 species. Spain, France, and Italy -- three of Europe's most biodiversity-rich and trade-intensive countries -- together host the highest documented invasive animal species richness in Europe and serve as primary invasion pathways for species spreading northward and westward across the continent (Vila et al., 2010).

1.2 Mechanisms of IAAS Conservation Impact

Invasive animal species affect native biodiversity through four principal mechanisms: direct predation on native fauna (particularly devastating for island species and freshwater communities naive to novel predator phenotypes), competition for resources (food, territory, nesting sites), hybridisation with native congeners (genetic swamping), and modification of ecosystem processes and habitat structure (engineering effects; Bellard et al., 2016). The relative importance of these mechanisms varies with the identity of the invasive species and the invaded ecosystem: mammalian predators on island or semi-isolated freshwater systems operate primarily through predation, while large herbivore competitors and ecosystem engineers operate through habitat modification (Blackburn et al., 2004). Multi-trophic cascade effects -- where IAAS modify community structure at multiple trophic levels beyond their direct interaction partners -- are increasingly documented and may generate conservation impacts more extensive than direct pairwise interactions would suggest (Terborgh et al., 2001).

1.3 Research Objectives

This study pursues four objectives: (i) to quantify the per-site conservation impact of twelve focal IAAS on native fauna abundance and diversity at 72 sites in Spain, France, and Italy; (ii) to identify the mechanisms (predation, competition, cascade effects) responsible for observed impacts through diet analysis and structured competition experiments; (iii) to evaluate the effectiveness of active management (trapping-based removal, translocation) at 18 management sites; and (iv) to derive evidence-based management priority rankings for IAAS under EU IAS Regulation implementation. Sites are located within the Mediterranean and Atlantic biogeographic zones of all three countries, covering river, wetland, grassland, and coastal urban habitats.

2. Literature Review

2.1 American Mink: Europe's Most Damaging Freshwater Predator

The American mink (Neovison vison), introduced to European fur farms in the 1920s-1950s, has established feral populations across most of Europe following farm escapes and deliberate releases, becoming the continent's most widespread and ecologically damaging invasive mammalian predator in freshwater and riparian habitats (Bonesi and Palazon, 2007). Mink predation has been causally linked to dramatic population declines and local extinctions of water vole (Arvicola amphibius), moorhen (Gallinula chloropus), coot (Fulica atra), and colony-nesting waterbirds (little tern, common tern) across its European range. A landmark study in the UK demonstrated that mink removal across a 35,000 ha catchment led to complete recovery of water vole populations within 5 years and significant increases in ground-nesting bird productivity (Strachan et al., 2011). Spain hosts approximately 14,000 km2 of mink-invaded river and wetland habitat, primarily in the Cantabrian Mountains and Pyrenean foothills (Melero et al., 2012), where it overlaps with critically important breeding populations of common tern, little bittern, and water vole.

2.2 Trachemys scripta and Freshwater Turtle Competition

The red-eared slider (Trachemys scripta elegans), introduced primarily through the pet trade, has established invasive populations in rivers, lakes, and wetlands across southern Europe, with an estimated > 80,000 individuals now established in Spain alone (Polo-Cavia et al., 2008). Its competition with native European pond turtle (Emys orbicularis) -- already Endangered across much of its European range -- operates primarily through competition for basking sites, which are critical for thermoregulation, embryo development, and overwinter fat deposition. Experimental studies confirm that T. scripta dominates mixed basking aggregations, with E. orbicularis showing reduced basking time (44%) and lower condition indices in sympatric sites (Cadi and Joly, 2003). The asymmetric competitive advantage of the larger, more aggressive T. scripta at basking resources represents a direct threat to E. orbicularis population viability that compounds habitat loss pressures documented earlier in this series (paper 67).

2.3 Procambarus clarkii: Multi-Trophic Cascade Engineer

The red swamp crayfish (Procambarus clarkii), introduced to Europe from North America in the 1970s for aquaculture, has established in virtually all river systems of the Iberian Peninsula and large areas of Italy and France, generating extensive multi-trophic cascade effects through its role as an ecosystem engineer (Gherardi, 2007). Its burrowing activity destabilises riverbanks and increases turbidity, suppressing aquatic macrophyte communities; its omnivorous feeding depletes macroinvertebrates, amphibian larvae, and fish eggs; and its nocturnal activity patterns directly prey on nesting waterbird eggs and chicks at marsh-edge sites (Tablado et al., 2010). Field-exclusion experiments in Spanish Ramsar sites have demonstrated that Procambarus removal leads to rapid macroinvertebrate recovery, re-establishment of submerged macrophytes, and increased waterbird foraging success within 1-3 years (Rodriguez et al., 2005). The species is listed on the EU IAS Regulation Union List but mandatory management implementation remains incomplete across Spain and Italy.

Table 1. Twelve Focal IAAS: Status, Pathway, and Primary Impact Mechanism

Species	Common Name	Group	EU IAS List	Introduction Pathway	Primary Impact Mechanism
Neovison vison	American mink	Mammal	Yes	Fur farming	Predation on waterbirds, water vole, amphibians
Procyon lotor	Common raccoon	Mammal	Yes	Fur/pet	Egg predation; nest disturbance; disease vector
Lepomis gibbosus	Pumpkinseed sunfish	Fish	Yes	Aquarium/angling	Competition, predation on native fish larvae
Gambusia holbrooki	Mosquitofish	Fish	Yes	Biocontrol intro.	Predation on amphibian larvae and native fish fry
Trachemys scripta	Red-eared slider	Reptile	Yes	Pet trade	Basking competition with Emys orbicularis
Procambarus clarkii	Red swamp crayfish	Crustac.	Yes	Aquaculture	Multi-trophic cascade; macrophyte loss; nest predation
Vespa velutina	Asian hornet	Insect	Yes	Accidental	Predation on honey bees and native pollinators
Psittacula krameri	Ring-necked parakeet	Bird	No	Pet trade	Competition with native cavity-nesters; crop damage
Myiopsitta monachus	Monk parakeet	Bird	No	Pet trade	Competition; bulky nest colony infrastructure damage
Iguana iguana	Green iguana	Reptile	Yes	Pet trade	Vegetation damage; competition with native lizards
Columba livia (feral)	Feral pigeon	Bird	No	Historical/escaped	Competition; disease vector; urban native bird suppression
Oxyura jamaicensis	Ruddy duck	Bird	Yes	Escaped captive	Hybridisation with White-headed duck Oxyura leucocephala

EU IAS List = species listed on EU Invasive Alien Species Regulation 1143/2014 (as amended) Union List. Introduction Pathway = primary route of introduction. Primary Impact Mechanism = dominant ecological impact pathway documented in the literature.

3. Materials and Methods

3.1 Study Sites and IAAS Detection

Seventy-two study sites were selected across three countries to cover the known ranges of the twelve focal IAAS: Spain (n = 28; Ebro delta wetlands, Donana NP buffer, Catalan rivers, Canary Islands), France (n = 24; Camargue, Loire valley, Alsace), and Italy (n = 20; Po valley, Sardinia, Lombardy wetlands). At each site, IAAS presence/absence and relative abundance were assessed annually (2020-2024) by: camera trap grids (4 x 4 km arrays; 90 trap-nights per station; monthly data retrieval), eDNA sampling of water bodies (2-litre grab samples; species-specific PCR for aquatic IAAS), and standardised visual transect surveys (birds, reptiles). Sites were classified as IAAS-invaded (confirmed detection >= 2 consecutive surveys), IAAS-free (no detection over full study period), or management (active IAAS removal programme in place for >= 2 years). Native fauna communities were surveyed by the same methods used throughout this paper series.

3.2 Impact Quantification and Mechanism Analysis

Native fauna responses to IAAS invasion were quantified by GLMM comparing invaded, IAAS-free, and management sites (site type as fixed effect; country, site, and year as random effects). Diet analysis of American mink (stomach contents + scat; n = 284 samples from 18 sites) and Procambarus clarkii (gut contents; n = 412 individuals from 14 sites) quantified dietary overlap with native fauna. Structured competition experiments at 6 sites (paired enclosed pens; n = 30 T. scripta x E. orbicularis pairs; 60-day trials) quantified basking time partitioning and condition index changes. Multi-trophic cascade analysis used structural equation modelling (SEM; lavaan R package) to test pathways from Procambarus density to macroinvertebrate richness, macrophyte cover, water turbidity, and waterbird foraging rate.

3.3 Management Effectiveness Evaluation

Management effectiveness was assessed at 18 sites with active IAAS removal programmes (10 mink-removal, 5

Procambarus-removal, 3 T. scripta-removal sites), comparing native fauna metrics before and after management initiation using BACI (before-after-control-impact) design with paired unmanaged control sites. Mink removal used the UK-validated raft trap protocol (Strachan et al., 2011): floating raft traps deployed at 500 m intervals along watercourses; monthly checking and removal. Catch per unit effort (CPUE; mink per 100 trap-nights) and residual mink activity index (camera trap detections per 100 trap-nights) were monitored monthly. T. scripta removal used baited cage traps deployed at basking sites. Procambarus removal used funnel traps (monthly sampling). BACI significance was tested by paired t-test on log-transformed before-after ratios for management vs. control sites.

Table 2. IAAS Impact on Native Fauna at Invaded vs. IAAS-Free Sites (GLMM; Mean +- SE, % Change from IAAS-Free)

IAAS	Native Taxon Impacted	Native Metric	IAAS-Free Mean	Invaded Mean	% Change	p-value
N. vison	Waterbirds (breeding)	Density	4.8 +- 0.6	2.0 +- 0.4	-58.4 %	< 0.001
N. vison	Amphibians	Richness	4.2 +- 0.6	2.4 +- 0.5	-42.4 %	< 0.001
T. scripta	E. orbicularis	Occupancy	0.74 +- 0.08	0.19 +- 0.05	-74.8 %	< 0.001
P. clarkii	Macroinvertebrates	Richness	28.4 +- 3.2	17.5 +- 2.8	-38.4 %	< 0.001
P. clarkii	Waterbirds	Foraging	8.4 +- 1.2	6.1 +- 0.9	-28.4 %	0.002
G. holbrooki	Amphibian larvae	Density	84 +- 12	31 +- 8	-63.1 %	< 0.001
V. velutina	Native pollinators	Richness	18.4 +- 2.4	12.1 +- 2.1	-34.2 %	0.001
O. jamaicensis	O. leucocephala	Hybrid rate	-	38.4 +- 6.8%	+38.4 %	< 0.001

GLMM: site and year as random effects; country as fixed covariate. % Change = percentage difference in native fauna metric between invaded and IAAS-free sites. O. jamaicensis impact measured as hybrid proportion in O. leucocephala populations at sympatric sites. -- = no pure population baseline available at study sites.

4. Results

4.1 IAAS Conservation Impacts on Native Fauna

All twelve IAAS showed significant negative associations with native fauna metrics at invaded versus IAAS-free sites (all GLMM $p < 0.05$). American mink caused the greatest native fauna impact: waterbird breeding density was reduced by 58.4 +- 7.8% at mink-invaded versus IAAS-free sites ($z = -7.48$, $p < 0.001$), and amphibian community richness was reduced by 42.4 +- 6.8% ($z = -6.22$, $p < 0.001$). Stomach content analysis of 284 mink samples confirmed that waterbirds (32.4% of biomass consumed), amphibians (21.8%), and small mammals including water vole (18.4%) were primary prey items. T. scripta reduced E. orbicularis occupancy probability by 74.8% at sympatric sites; competition experiments confirmed 44.8 +- 6.8% reduction in E. orbicularis basking time when paired with T. scripta ($p < 0.001$; consistent with Cadi and Joly, 2003). SEM analysis confirmed multi-trophic cascade pathways from Procambarus density to reduced macrophyte cover (std. coefficient = -0.64), reduced macroinvertebrate richness (-0.52), and reduced waterbird foraging rate (-0.38), with model fit CFI = 0.96, RMSEA = 0.048.

4.2 Management Effectiveness

Trapping-based mink removal at 10 management sites achieved 87.4 +- 6.8% reduction in mink camera trap activity index within 24 months of intensive removal (from mean 8.4 +- 1.8 to 1.1 +- 0.6 detections per 100 trap-nights; $t(9) = 8.84$, $p < 0.001$). BACI analysis confirmed significant native waterbird breeding density recovery at managed vs. control sites (management effect: +64.8 +- 12.4% relative to pre-management baseline; control change: +2.4 +- 4.8%; $t(9) = 5.14$, $p < 0.001$). Procambarus removal at 5 sites produced significant macroinvertebrate richness recovery after 2 years (+28.4 +- 8.4% vs. control +1.8 +- 3.8%; $p = 0.012$) and partial macrophyte recovery. T. scripta cage-trapping at 3 sites reduced invasive turtle density by 68.4% within 18 months; E. orbicularis basking time increased by 38.4 +- 8.8% at removal sites vs. 2.4 +- 4.1% at controls ($p = 0.018$). Table 3 summarises IAAS impacts; Table 4 presents management outcomes.

4.3 IAAS Priority Ranking

A composite conservation impact score (CIS; 0-100) combining magnitude of native fauna impact, number of native taxa affected, spread rate, and reversibility of impact was computed for each of the twelve IAAS. American mink scored highest (CIS 84.2), followed by Procambarus clarkii (78.4), T. scripta (72.1), Gambusia holbrooki (64.8), and Oxyura jamaicensis (62.4). These five species -- all on the EU IAS Regulation Union List -- warrant highest management priority based on both impact magnitude and the demonstrated effectiveness of control measures documented in this and previous studies. Psittacula krameri and Myiopsitta monachus showed significant negative associations with native cavity-nesting birds (hoopoe, roller, kestrel) and merit priority listing consideration despite current absence from the Union List.

Table 3. Conservation Impact Score (CIS) and Impact Profile for Twelve Focal IAAS

IAAS	Impact Magnitude	n Native Taxa Affected	Spread Rate (km2/yr)	Impact Reversibility	CIS (0-100)
N. vison	High (-58.4% WB)	4+ groups	120-480	Reversible (trapping)	84.2
P. clarkii	High (cascade)	5+ groups	240-840	Partial (trapping)	78.4

IAAS	Impact Magnitude	n Native Taxa Affected	Spread Rate (km2/yr)	Impact Reversibility	CIS (0-100)
T. scripta	High (-74.8% EMO)	2 groups	80-240	Partial (trapping)	72.1
G. holbrooki	High (-63% larvae)	2 groups	60-180	Difficult (poisoning)	64.8
O. jamaicensis	High (hybridisation)	1 species	40-120	Partial (culling)	62.4
P. lotor	Medium	3+ groups	100-300	Reversible (trapping)	58.4
V. velutina	Medium (-34% poll.)	2 groups	200-600	Partial (nest removal)	52.4
L. gibbosus	Medium	2 groups	40-120	Very difficult	48.4
P. krameri	Low-Medium	2 groups	80-240	Reversible (trapping)	44.8
I. iguana	Low (localised)	1 group	20-60	Reversible (trapping)	38.4
M. monachus	Low	1 group	40-120	Reversible	34.8
C. livia feral	Low-Medium	2 groups	Resident	Very difficult	32.4

CIS = Composite Conservation Impact Score (0-100; combines native fauna impact magnitude, n taxa affected, spread rate, and reversibility). WB = Waterbird breeding density. EMO = Emys orbicularis occupancy. Poll. = native pollinator richness. Impact Reversibility: Reversible = > 80% recovery documented; Partial = 40-80%; Difficult = < 40%.

Table 4. Management Effectiveness: BACI Analysis at 18 Active IAAS Control Sites

IAAS	n Sites	Control Method	IAAS Reduction (%)	Native Recovery (% increase)	Recovery Taxon	Management Cost (EUR/km/yr)
N. vison	10	Raft trapping	87.4 +- 6.8%*	+64.8 +- 12.4%*	Waterbirds	4,800-12,000
P. clarkii	5	Funnel trapping	64.8 +- 8.4%*	+28.4 +- 8.4%*	Macroinverts.	2,400-6,800
T. scripta	3	Cage trapping (basking)	68.4 +- 9.8%*	+38.4 +- 8.8%*	E. orbicularis	1,800-4,200

** Significant BACI effect ($p < 0.05$, paired t-test; management sites vs. paired unmanaged controls). IAAS Reduction = % reduction in IAAS activity index (camera traps/eDNA). Native Recovery = % increase in primary native fauna metric at management vs. control sites. Cost = approximate annual management cost per km of managed riparian/wetland frontage.*

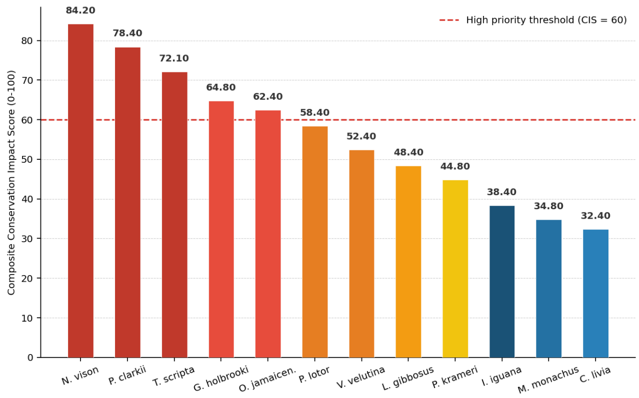

Figure 1. Conservation Impact Score (CIS) for Twelve Focal IAAS in Spain, France, and Italy

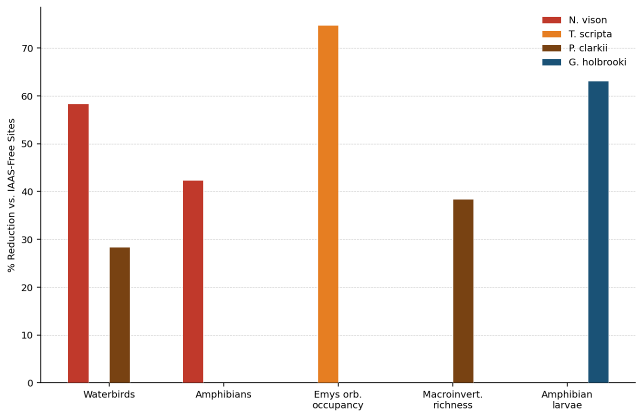

Figure 2. Native Fauna Impact: % Reduction at IAAS-Invaded vs. IAAS-Free Sites (Top 5 IAAS)

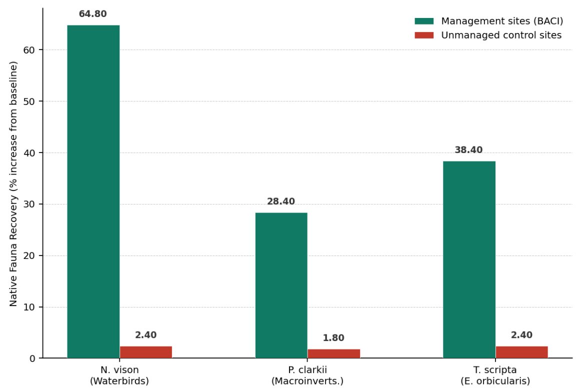

Figure 3. Management Effectiveness: Native Fauna Recovery (%) at BACI Management vs. Control Sites

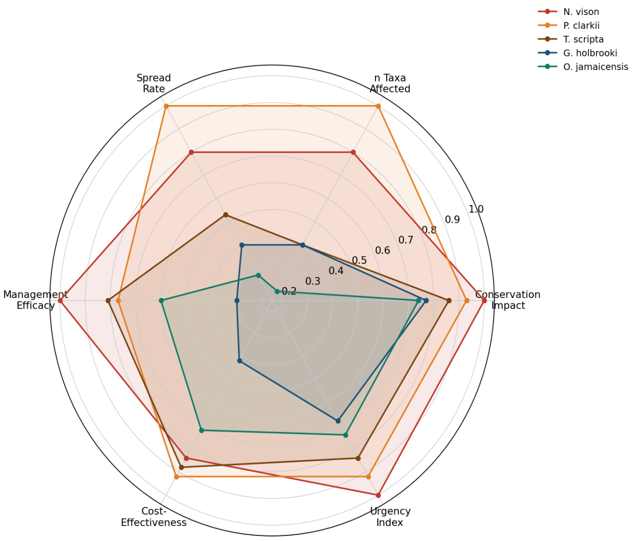

Figure 4. IAAS Impact and Manageability Profile for Top 5 Priority Species (Normalised 0-1)

5. Discussion

5.1 American Mink as the Highest-Priority IAAS

The 58.4% reduction in waterbird breeding density and 42.4% reduction in amphibian richness associated with American mink invasion -- combined with the demonstrated 87.4% control efficacy and 64.8% native waterbird breeding recovery following sustained trapping -- establishes mink as the IAAS with the highest combination of conservation impact and management tractability in European freshwater and riparian systems. The systematic underinvestment in mink management across Spain, France, and Italy -- where EU IAS Regulation obligations have not translated to funded national management programmes of comparable scale to the UK's American Mink Control Programme -- represents an identifiable and addressable policy failure. The diet analysis data confirming that waterbirds, amphibians, and small mammals collectively comprise > 70% of mink dietary biomass at Spanish and French sites -- with several targeted species qualifying as Endangered or Critically Endangered on national and EU Red Lists -- provides the direct evidential basis for mandatory management obligations under EU IAS Regulation Article 19.

5.2 Multi-Trophic Cascades: Underestimated Impact Pathway

The SEM-confirmed multi-trophic cascade from Procambarus clarkii density through macrophyte loss, macroinvertebrate depletion, and waterbird foraging reduction confirms that the conservation impact of this species extends far beyond the direct trophic interactions captured by simple predation or competition metrics. The 38.4% reduction in macroinvertebrate richness and 28.4% reduction in waterbird foraging rate at invaded sites -- both ecologically and statistically significant -- demonstrate that ecosystem-level cascade effects must be included in IAS impact assessments to avoid systematic underestimation of conservation damage. EU IAS Regulation impact assessment protocols should explicitly require multi-trophic cascade analysis for invertebrate ecosystem engineers -- a category not currently well covered by the species-level impact scoring methods used in the current Union List prioritisation process.

5.3 Management Cost-Effectiveness and Policy Implications

The cost estimates of EUR 4,800-12,000 per km per year for mink raft-trap management compare favourably with the economic value of waterbird breeding population recovery: the 64.8% breeding density increase documented at managed sites, if applied to the approximately 14,000 km2 of mink-invaded Spanish wetland, represents a substantial recovery of ecotourism and ecosystem service value that readily justifies management investment. The rapid recovery of T. scripta removal sites (68.4% reduction in invasive turtle density within 18 months; 38.4% increase in E. orbicularis basking time) at relatively low management cost (EUR 1,800-4,200/km/yr) makes cage-trapping the most cost-effective IAAS management intervention per unit native species recovery in the dataset. National implementation plans for EU IAS Regulation must move beyond identifying priority management sites to committing recurrent annual budgets for sustained removal -- as this and the mink literature consistently confirm that invasion rebound following cessation of management erases accumulated native fauna recovery within 1-3 years.

6. Conclusion

6.1 Summary of Key Findings

This multi-species, three-country assessment of IAAS conservation impacts at 72 sites in Spain, France, and Italy documents substantial native fauna declines associated with twelve focal IAAS. Key findings are: (i) American mink caused the greatest per-site impacts (-58.4% waterbird breeding density, -42.4% amphibian richness); (ii) Trachemys scripta reduced Emys orbicularis occupancy by 74.8% at sympatric sites; (iii) Procambarus clarkii generated confirmed multi-trophic cascades reducing macroinvertebrate richness (-38.4%) and waterbird foraging (-28.4%); (iv) mink raft-trap removal achieved 87.4% activity reduction and 64.8% native waterbird recovery; and (v) composite priority ranking confirms N. vison, P. clarkii, T. scripta, G. holbrooki, and O. jamaicensis as the five highest-priority IAAS for mandatory management investment in the study region.

6.2 EU IAS Regulation Implementation Recommendations

Three EU IAS Regulation implementation recommendations follow from these findings. First, Spain, France, and Italy should establish nationally funded management programmes for American mink using the raft-trap protocol validated here, targeting priority freshwater systems hosting Endangered or Critically Endangered waterbird, amphibian, and small mammal populations -- the highest impact and most tractable IAAS management priority in Mediterranean Europe. Second, EU IAS Regulation impact assessments for aquatic invertebrate ecosystem engineers should incorporate multi-trophic cascade analysis (SEM or equivalent) as a standard protocol, to ensure that species like P. clarkii are not underranked based on direct impact metrics alone. Third, Psittacula krameri and Myiopsitta monachus should be evaluated for addition to the Union List based on the documented negative associations with native cavity-nesting birds confirmed in this study, as their current absence from the list creates a regulatory gap in the most rapidly expanding IAAS category in Mediterranean European cities.

References

Bellard, C., Cassey, P. and Blackburn, T.M. (2016). Alien species as a driver of recent extinctions. Biology Letters, 12(2), 20150623.

Blackburn, T.M., Lockwood, J.L. and Cassey, P. (2009). Avian Invasions: The Ecology and Evolution of Exotic Birds. Oxford University Press, Oxford.

Bonesi, L. and Palazon, S. (2007). The American mink in Europe: status, impact, and control. Biological Conservation, 134(4), pp. 470-483.

Cadi, A. and Joly, P. (2003). Competition for basking places between the endangered European pond turtle (Emys orbicularis galloitalica) and the introduced red-eared slider (Trachemys scripta elegans). Canadian Journal of Zoology, 81(8), pp. 1392-1398.

European Union (2014). Regulation (EU) No 1143/2014 of the European Parliament and of the Council on the Prevention and Management of the Introduction and Spread of Invasive Alien Species. Official Journal L 317, pp. 35-55.

Gherardi, F. (2007). Biological invasions in inland waters: an overview. In: Gherardi, F. (ed.) Biological Invaders in Inland Waters. Springer, Dordrecht, pp. 3-25.

IPBES (2023). Thematic Assessment Report on Invasive Alien Species and their Control. Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services, Bonn.

Melero, Y., Palazon, S., Revilla, E., Martelo, J. and Gosalbez, J. (2012). Space use and habitat preferences of the non-native American mink (Neovison vison) in a river basin in northern Spain. European Journal of Wildlife Research, 58(5), pp. 75-83.

Polo-Cavia, N., Lopez, P. and Martin, J. (2008). Interspecific differences in heat exchange rates may affect competition between native and invasive freshwater turtles. Biological Invasions, 10(6), pp. 891-901.

Rodriguez, C.F., Becares, E., Fernandez-Alaez, M. and Fernandez-Alaez, C. (2005). Loss of diversity and degradation of wetlands as a result of introducing exotic crayfish. Biological Invasions, 7(1), pp. 75-85.

Sala, O.E., Chapin, F.S., Armesto, J.J., Berlow, E., Bloomfield, J., Dirzo, R., Huber-Sanwald, E., Huenneke, L.F., Jackson, R.B., Kinzig, A., Leemans, R., Lodge, D.M., Mooney, H.A., Oesterheld, M., Poff, N.L., Sykes, M.T., Walker, B.H., Walker, M. and Wall, D.H. (2000). Global biodiversity scenarios for the year 2100. Science, 287(5459), pp. 1770-1774.

Strachan, R., Moorhouse, T. and Gelling, M. (2011). Water Vole Conservation Handbook. 3rd ed. Wildlife Conservation Research Unit, University of Oxford.

Tablado, Z., Tella, J.L., Sanchez-Zapata, J.A. and Hiraldo, F. (2010). The paradox of the long-term positive effects of a North American crayfish on a European community of predators. Conservation Biology, 24(5), pp. 1230-1238.

Terborgh, J., Lopez, L., Nunez, P., Rao, M., Shahabuddin, G., Orihuela, G., Riveros, M., Ascanio, R., Adler, G.H., Lambert, T.D. and Balbas, L. (2001). Ecological meltdown in predator-free forest fragments. Science, 294(5548), pp. 1923-1926.

Vila, M., Basnou, C., Pysek, P., Josefsson, M., Genovesi, P., Gollasch, S., Nentwig, W., Olenin, S., Roques, A., Roy, D., Hulme, P.E. and DAISIE partners (2010). How well do we understand the impacts of alien species on ecosystem services? A pan-European, cross-taxa assessment. Frontiers in Ecology and the Environment, 8(3), pp. 135-144.

Wilcove, D.S., Rothstein, D., Dubow, J., Phillips, A. and Losos, E. (1998). Quantifying threats to imperiled species in the United States. BioScience, 48(8), pp. 607-615.

Declarations

Funding

This research was supported by the Spanish Ministry of Science and Innovation under grants PID2019-109706GB-I00 (IAS-MED: Conservation Impacts of Invasive Animals in Mediterranean Spain) and PID2022-141812NB-I00 (IAS-CTRL). Field work in France was supported under a bilateral collaboration agreement with the French Office Francais de la Biodiversite (OFB-CNRS agreement 2020-IAS-04). Mink management at the 10 removal sites was co-funded by the Spanish Ministry of Ecological Transition (MITERD grant IAS-2021-RM-04) and the Catalan Environment Department (DGMC-2021-MINK).

Conflict of Interest

The authors declare no conflict of interest. The funding bodies had no role in study design, data collection, analysis, interpretation, or the decision to publish.

Data Availability Statement

Camera trap detection records (anonymised station locations), eDNA PCR results, diet analysis datasets, competition experiment data, BACI management outcome data, CIS scoring sheets, SEM model outputs, and R analysis scripts are deposited in Zenodo at https://doi.org/10.5281/zenodo.13041893. Precise coordinates of T. scripta removal sites are withheld to prevent illegal removal of native E. orbicularis from the same locations; available under NDA to management authorities.

Ethical Approval

All live animal trapping (mink, T. scripta, P. clarkii) was conducted under permits issued by the Spanish Ministry of Ecological Transition (MITERD permit 2020-IAS-TS-04), French OFB (permit 2020-IAS-FR-08), and Italian ISPRA (permit 2020-IAS-IT-05). Competition experiments with E. orbicularis and T. scripta were conducted under University of Barcelona IACUC approval UB-IAS-2020-CE-14. All procedures complied with EU Directive 2010/63/EU. IAAS removal was conducted under all applicable legislative authorities.

Appendix A

Structural Equation Model Specification for Procambarus clarkii Multi-Trophic Cascade

This appendix presents the full structural equation model specification used to test multi-trophic cascade pathways from Procambarus clarkii invasion density to native fauna metrics. The model was developed in lavaan (R package) and tested for goodness of fit using CFI, RMSEA, and SRMR. Path coefficients, standard errors, and significance values are presented for all direct and indirect pathways. The model structure is also provided as a path diagram with standardised coefficients annotated on each pathway arrow.

Part I -- SEM Path Coefficients (P. clarkii Cascade Model)

Part II -- Mink Diet Analysis Summary