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# Detailed assessment of the reported economic costs of invasive species in Australia

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## Abstract

The legacy of deliberate and accidental introductions of invasive alien species to Australia has had a hefty economic toll, yet quantifying the magnitude of the costs associated with direct loss and damage, as well as for management interventions, remains elusive. This is because the reliability of cost estimates and under-sampling have not been determined. We provide the first detailed analysis of the reported costs associated

with invasive species to the Australian economy since the 1960s, based on the recently published InvaCost database and supplementary information, for a total of 2078 unique cost entries. Since the 1960s, Australia has spent or incurred losses totalling at least US\$298.58 billion (2017 value) or AU\$389.59 billion (2017 average exchange rate) from invasive species. However, this is an underestimate given that costs rise as the number of estimates increases following a power law. There was an average 1.8–6.3-fold increase in the total costs per decade since the 1970s to the present, producing estimated costs of US\$6.09–57.91 billion year<sup>-1</sup> (all costs combined) or US\$225.31 million–6.84 billion year<sup>-1</sup> (observed, highly reliable costs only). Costs arising from plant species were the highest among kingdoms (US\$151.68 billion), although most of the costs were not attributable to single species. Of the identified weedy species, the costliest were annual ryegrass (*Lolium rigidum*), parthenium (*Parthenium hysterophorus*) and ragwort (*Senecio jacobaea*). The four costliest classes were mammals (US\$48.63 billion), insects (US\$11.95 billion), eudicots (US\$4.10 billion) and monocots (US\$1.92 billion). The three costliest species were all animals – cats (*Felis catus*), rabbits (*Oryctolagus cuniculus*) and red imported fire ants (*Solenopsis invicta*). Each State/Territory had a different suite of major costs by species, but with most (3–62%) costs derived from one to three species per political unit. Most (61%) of the reported costs applied to multiple environments and 73% of the total pertained to direct damage or loss compared to management costs only, with both of these findings reflecting the availability of data. Rising incursions of invasive species will continue to have substantial costs for the Australian economy, but with better investment, standardised assessments and reporting and coordinated interventions (including eradications), some of these costs could be substantially reduced.

### Abstract in Pitjantjatjara

**Kuka munu ukiri kutjupa tjuṅanku manta nganampa kurantja alatjitu.** Kuḷi kutjupa kuḷi kutjupa aṅangu kutjupa tjuṅanku kuka kutjupa kutjupa tjuṅa munu punu kutjupa kutjupa tjuṅa ngura kutjupa pararinguru ngalya-katipai Australiala-kutu. Ka kuka munu punu nyanga malikitja tjuṅanku ngura nganampa kuralpai alatjitu, kala palulanguru nganaṅa mani pulkangka payamilalpai ngura wiṛura kanyintjik-itjanku, mani nampa nyangangka 6,000,000,000 dollars, mani pulka mulata. Palu nganaṅa mani pulka mulata manti payamilalpai mani panya palula munkara alatjitu, panya nganaṅa tjukutjukuku kutju ninti kukaku munu punuku paluru tjana panya manta nyanga kurannyangka. Panya kuka munu punu tjuṅanku manti ngura nyanga palunya pulkara kurani, kala tjukutjukuku kutju nintiringu. Ka kutjupa tjuṅanku ngura kutjupanguru uninypa kura ngalya-katira manta nyanga palula para-wanira wanannyangka ukiri kura mulapa pakara pulkaringkupai munu lipiringkupai manta winkingka uninypa panya palulanguru, munu manta kuralpai alatjitu. Ka pala palu purunytyju kuka kutjupa tjuṅanku pulkara kuralpai manta nyanga nganampa, kuka nyangantu: गया, putji, rapita munu minga kura, minga panya mututa, pikati pulka. Kuka nyanga paluru tjana manta kuralpai alatjitu ukiringka munkara alatjitu. Tjinguru aṅangu tjuṅanku titutjaranku kutjupa kutjupa tjuṅa ngura kutjupa-nguru ngalya-katinyangkampa ka paluru tjana pulkara kuralku manta nyanga palunya. Palu nganaṅa uti manta panya wiṛura kanyinma, kutjupa tjuṅanku kurantjaku-tawara. Munu palulanguru nganaṅa mani pulkangka payamilantja wiya ngura nyangatja palya ngaranyangka.

### Abstract in Chinese

#### 对澳大利亚已报道的入侵物种造成经济损失的详细评估

无意和有意引入的外来入侵物种已经给澳大利亚的经济造成了巨大损失。然而，对生物入侵造成的经济损失和相应的管理投入进行定量仍较困难，因为我们当前缺乏可靠且全面的生物入侵造成经济损失的数据。为填补这一空缺，我们利用最近发表的InvaCost数据库及其相应的补充信息，根据自20世纪60年代以来报道的2078条数据，首次分析了生物入侵对澳大利亚经济造成的损失。自20世纪60年代以来，生物入侵已经给澳大利亚造成了至少2985.8亿美元（2017年的价值）或3895.9亿澳元的经济损失（2017年的平均汇率）。然而，这一数字仍被

低估，因为经济损失会随着数据数量的增加而呈幂律上升。20世纪70年代至今，经济损失平均每十年便会增加1.8–6.3倍，其对应的增长速度为60.9–57.1亿美元/年（所有损失的数据）或2.2531亿–68.4亿美元/年（仅考虑实测到的且可靠较高的数据）。外来植物入侵产生的损失为各生物界中最高的（1516.8亿美元），尽管大部分的损失不是由单一物种造成。在已确定的入侵杂草中，造成经济损失最高的物种是硬直黑麦草 (*Lolium rigidum*)、银胶菊 (*Parthenium hysterophorus*) 和新疆千里光 (*Senecio jacobaea*)。造成经济损失最高的四个类群分别是哺乳动物（486.3亿美元）、昆虫（119.5亿美元）、真双子叶植物（41.0亿美元）和单子叶植物（19.2亿美元）。造成经济损失最高的三个物种都是动物，分别为家猫 (*Felis catus*)、家兔 (*Oryctolagus cuniculus*) 和入侵红火蚁 (*Solenopsis invicta*)。每个州/领地的主要经济损失由不同物种造成，但是各行政单元的大多数（3–62%）损失可归于一至三个物种。大多数（61%）经济损失是由入侵物种在多个环境中造成的，且73%的总损失与直接的经济损失相关，而非与管理投入相关。这两个结果反映了数据的可用性。日益增多的入侵物种将持续对澳大利亚的经济造成巨大损失。但是，如果有更合理的经费投入、标准化的评估和报告、以及协调的干预措施（包括根除），生物入侵造成的经济损失可被极大地降低。

### Abstract in Bahasa Indonesia

#### Kajian lengkap mengenai kerugian ekonomi yang diakibatkan oleh spesies invasif di Australia.

Dampak dari masuknya spesies invasif, baik secara sengaja maupun tidak, ke dalam Australia telah mengakibatkan kerugian perekonomian yang besar, namun mengukur besarnya kerugian yang terkait biaya dan kerusakan secara langsung, juga terkait pengeluaran untuk manajemen intervensi, masih sulit untuk dilakukan. Hal ini karena tingkat keandalan dari estimasi kerugian dan pengambilan sampel belum diketahui. Di sini kami memaparkan analisis mendetil untuk pertama kalinya mengenai kerugian yang terkait dengan keberadaan spesies invasif terhadap perekonomian Australia sejak tahun 1960an, berdasarkan *database* InvaCost yang baru-baru ini dipublikasikan dan informasi tambahan lainnya, dengan total 2078 buah entri unik terkait biaya kerugian. Sejak tahun 1960an, Australia telah mengeluarkan atau mengalami kerugian yang mencapai setidaknya US\$295.58 milyar (nilai tahun 2017) atau AU\$389.59 milyar (nilai tukar 2017) akibat keberadaan spesies invasif. Namun, nilai ini masih merupakan estimasi yang lebih rendah dari yang sesungguhnya dikarenakan oleh peningkatan kerugian secara eksponensial seiring bertambahnya data. Secara rata-rata terdapat peningkatan secara 1.8–6.3 kali dari biaya kerugian total untuk setiap dekade sejak 1970an hingga sekarang, menghasilkan estimasi kerugian sebesar US\$6.09–57.91 milyar per tahun (seluruh biaya disatukan) atau US\$225.31 juta–6.84 milyar per tahun (teramati, hanya nilai kerugian yang dapat diandalkan). Kerugian yang dihasilkan dari spesies tumbuhan paling tinggi diantara kingdom yang lain (US\$151.68 milyar), namun sebagian besar dari kerugian ini tidak diakibatkan oleh spesies tunggal. Dari tanaman rumput liar yang teridentifikasi, yang paling besar mengakibatkan kerugian adalah rumput *Lolium rigidum*, rumput *Parthenium hysterophorus*, dan rumput *Senecio jacobaea*. Untuk tingkatan kelas, yang mengakibatkan kerugian paling besar adalah mamalia (US\$48.63 milyar), serangga (US\$11.95 milyar), tanaman dikotil sejati/eudikot (US\$4.10 milyar) dan monokotil (US\$1.92 milyar). Untuk tingkatan spesies, tiga spesies yang paling mengakibatkan kerugian adalah spesies hewan, yaitu kucing (*Felis catus*), kelinci (*Oryctolagus cuniculus*) dan semut api (*Solenopsis invicta*). Setiap negara bagian memiliki pola kerugian terbesar yang berbeda berdasarkan jenis spesies, namun kerugian terbesar (3–62%) datang dari satu hingga tiga spesies per unit politik. Sebagian besar (61%) dari kerugian yang dilaporkan terjadi pada beberapa jenis lingkungan dan 73% dari keseluruhan termasuk ke dalam kerusakan atau kerugian secara langsung dibandingkan dengan biaya manajemen saja, dengan catatan bahwa kedua penemuan ini mencerminkan ketersediaan data. Peningkatan masuknya spesies invasif akan terus menghasilkan kerugian yang nyata untuk perekonomian Australia, namun dengan investasi yang lebih baik, penyeragaman dari pengukuran dan pelaporan dan juga pengkoordinasian intervensi (termasuk pembasmian), beberapa kerugian ini dapat dikurangi secara substansial.

### Abstract in Tok Pisin

**Stadi lon painim aut kostim lon ol nogut binatang na diwai kam insait lon Austrelia.** Taim ol nogut binatang na diwai bilong longwe ples kamap lo Austrelia, ol bagarapim kantri stret. Tasol em hatwok yet lon lukim hamas stret moni dispela bagarap em givim lo kantri. Dispela em bikos nogat gutpela stadi lo kostim em kamap yet. Tasol nau, dispela em nambawan stadi em lukluk lon hamas stret moni Austrelia usim lon lukautim na managim dispela wari (lon ol nogut binatang na diwai kam insait lo kantri), lon 1960s kam inap nau; ol wokman lo stadi lukluk lon kainkain save lon mekim dispela kostim. Bifo lon 1960s kam inap nau, Austrelia givim moni mak olsem US\$298.58 billion (lon 2017) or AU\$389.59 billion (lon 2017 namel namba) lo lukautim ol yet lon binatang nogut. Tasol dispela moni mak em ino stret tumas bilong wanem ol namba save senis olgeta taim. Na tu, lon 1970s kam, ibin gat 1.8–6.3% moa kostim olgeta tenpela yia kam inap tede, moni mak olsem US\$6.09–57.91 billion yia-1 (olgeta kostim wantaim) or US\$225.31 million–6.84 billion. Ol kostim bilong olgeta nogut diwai wantaim em bikpela olgeta (US\$151.68 billion). Lo sait blo gras nogut, sampela olsem *ryegrass* (*Lolium rigidum*), *parthenium* (*Parthenium hysterophorus*) na *ragwort* (*Senecio jacobaea*) em planti moni stret. Na tu, lon sait lon banisim ol abus, ol *mammal* (US\$48.63 billion), binatang (US\$11.95 billion), *eudicots* (US\$4.10 billion) na *monocot* (US\$1.92 billion) usim planti moni tu. Lon sait lon banisim olgeta abus wantaim, ol pusi (*Felis catus*), *rabbit* (*Oryctolagus cuniculus*) na retpela paia anis (*Solenopsis invicta*) usim bikpela moni stret. Olgeta provins lo Austrelia givim planti moni lo lukautim ol yet lon ol nogut binatang na diwai, tasol dispela moni ol givim (3–62%) save go lon wanpla or tripela binatang/diwai nogut tasol. Planti lon dispela moni (61%) em ol provins givim lon lukautim planti kainkain bus/bikbus insait lo graun blo ol, na 73% lo dispela olgeta moni em ol usim lon lukautim bus/bikbus we binatang bagarapim pinis; ol no usim moni lo sait lo lukautim bifo bus/bikbus bagarap. Tede, ol nogut binatang na diwai kam insait lo Austrelia na wok lon bagarapim kantri yet, tasol sapos igat moa moni, and tu ol ripot na wok bung wantaim kamap, sampela dispela ol kostim bai go daun.

### Abstract in French

**Estimation de l'ensemble des coûts économiques des espèces exotiques envahissantes en Australie.** L'histoire des introductions intentionnelles et accidentelles des espèces exotiques envahissantes en Australie a un coût économique élevé. La quantification de l'ampleur de ce coût associé aux pertes directes ainsi qu'aux dommages demeure pourtant inconnue. La difficulté d'arriver à une estimation robuste du montant total est exacerbée par un échantillonnage insuffisant et un manque de protocoles pour déterminer la robustesse des estimations de coûts individuels. Nous fournissons le premier bilan des coûts associés aux espèces envahissantes à l'économie australienne depuis les années 1960, à partir de la base de données InvaCost récemment publiée, enrichie d'estimations supplémentaires. À partir de 2078 estimations uniques de coûts, nous estimons que l'Australie a subi un coût total de US\$298,58 milliards (valeur 2017, soit AU\$389,59 milliards). Ce total doit cependant être une sous-estimation parce que les coûts augmentent exponentiellement avec le nombre d'estimations. Le taux d'augmentation des coûts par décennie était de 1,8 à 6,3 fois depuis les années 1970 jusqu'au présent, ce qui indique un montant annuel de US\$6,09–57,91 milliards (tous les coûts compris), soit US\$2,25 millions à 6,84 milliards par an (coûts observés et robustes uniquement). Les coûts associés aux espèces végétales (US\$151,68 milliards) étaient les plus élevés parmi les règnes que nous avons considérés, même si la plupart de ce montant était associée aux groupements d'espèces et non aux espèces individuelles. Parmi les plantes, les coûts les plus élevés sont venus de l'ivraie raide (*Lolium rigidum*), l'absinthe marron (*Parthenium hysterophorus*) et le séneçon jacobé (*Senecio jacobaea*). Les classes les plus coûteuses étaient respectivement les mammifères (US\$48,63 milliards), les insectes (US\$11,95 milliards), les Eudicotylédones (US\$4,10 milliards) et les Monocotylédones (US\$1,92 milliards). Les espèces individuelles les plus coûteuses étaient tous les animaux : le chat haret (*Felis catus*), le lapin européen (*Oryctolagus cuniculus*) et la fourmi de feu (*Solenopsis invicta*). Le bilan de

coûts dominants diffèrent selon l'unité politique (états et territoires), mais la plupart (entre 3 et 62% selon l'unité politique) provenait d'une à trois espèces. La majorité (61%) des coûts se rapportait aux plusieurs environnements et 73% du montant total était associés aux dommages ou aux pertes directes (ex, coûts de gestion), qui reflètent la disponibilité des données. L'augmentation des espèces exotiques envahissantes va occasionner des coûts considérables à l'économie australienne dans les années à venir. De meilleurs investissements, des évaluations standardisées, et des interventions bien organisées pourraient cependant contribuer à une réduction considérable des coûts venant des espèces exotiques envahissantes dans le pays.

### Abstract in Spanish

**Evaluación detallada de los costos económicos registrados de las especies invasoras en Australia.** El legado de introducciones deliberadas y accidentales de especies exóticas invasoras en Australia ha tenido un costo económico considerable, sin embargo la cuantificación de la magnitud de los costos asociados con las pérdidas y daños directos, así como de las intervenciones de manejo, sigue siendo difícil de realizar. Esto se debe a que no se ha determinado la confiabilidad de las estimaciones de costos y el submuestreo. En este trabajo, proporcionamos el primer análisis detallado de los costos reportados asociados a especies invasoras para la economía australiana desde la década de 1960, basado en la base de datos InvaCost recientemente publicada e información complementaria para un total de 2078 registros únicos de costos. Desde la década de 1960, Australia ha gastado o incurrido en pérdidas un total de al menos US \$298,58 mil millones (valor de 2017) o AU \$389,59 mil millones (tipo de cambio promedio de 2017) debido a especies invasoras. Sin embargo, esto es una subestimación dado que los costos aumentan a medida que aumenta el número de estimaciones siguiendo una ley de potencia. Hubo un aumento promedio de 1.8 a 6.3 veces en los costos totales por década desde la década de 1970 hasta el presente, produciendo costos estimados de US \$6,09 a 57,91 mil millones año<sup>-1</sup> (todos los costos combinados) o US \$225,31 millones a US \$6,84 mil millones año<sup>-1</sup> (solo costos observados, altamente confiables). Los costos derivados de especies de plantas fueron los más altos entre todos los reinos (US \$151,68 mil millones), aunque la mayoría de los costos no se atribuyeron a una sola especie. De las especies de malezas identificadas, las más costosas fueron el raigrás anual (*Lolium rigidum*), la falsa altamisa (*Parthenium hysterophorus*) y la hierba cana (*Senecio jacobaea*). Las cuatro clases más costosas fueron mamíferos (US \$48,63 mil millones), insectos (US \$11,95 mil millones), eudicotiledoneas (US \$4,10 mil millones) y monocotiledóneas (US \$1,92 mil millones). Las tres especies que produjeron los mayores costos fueron animales: gatos (*Felis catus*), conejos (*Oryctolagus cuniculus*) y hormigas rojas importadas (*Solenopsis invicta*). Cada estado / territorio tuvo un conjunto diferente de costos principales por especie, pero la mayoría de los costos (3–62%) derivaron de una a tres especies por unidad política. La mayoría (61%) de los costos reportados aplicaron a múltiples hábitats y el 73% del total de costos correspondió a daños o pérdidas directas en comparación con los costos de manejo únicamente, ambos hallazgos reflejan la disponibilidad de datos. El aumento de las incursiones de especies invasoras seguirá teniendo costos sustanciales para la economía australiana, pero con una mejor inversión, estandarización de evaluaciones y de informes e intervenciones coordinadas (incluidas las erradicaciones), algunos de estos costos podrían reducirse considerablemente.

### Abstract in Portuguese

**Avaliação detalhada dos registros de custos econômicos associados a espécies invasoras na Austrália.** O legado de introduções deliberadas e acidentais de espécies exóticas invasoras na Austrália tem resultado em custos econômicos consideráveis. Contudo, calcular a magnitude dos custos associados a perdas diretas e danos, bem como dos custos associados com intervenções de gestão, não é imediato. Este desfazamento está relacionado com o nível indeterminado de confiança nas estimativas de custo e com a sub-amostragem. Nós providenciamos a primeira análise detalhada dos registros australianos de custos associados a espécies invasoras desde os anos 60, com base na publicação recente da database InvaCost e

respectiva informação complementar, para o total de 2078 registos únicos de custo. Desde a década de 1960, a Austrália incorreu um gasto total de, no mínimo, US\$298.58 mil milhões (valor de 2017) ou AU\$389.59 mil milhões (ao câmbio medio de 2017) devido a espécies invasoras. Este valor está contido subestimado, uma vez que o custo aumenta com o aumento de estimativas de custo de acordo com o modelo da lei de potência. Houve, em média, um aumento de 1.8 a 6.3 vezes no custo total por década desde os anos 70 até ao presente, levando a uma estimativa de custo de US\$6.09 a 57.91 mil milhões ano<sup>-1</sup> (para todos os custos combinados) ou US\$225.31 milhões a 6.84 mil milhões ano<sup>-1</sup> (só para custos observados, de elevada confiança). Os custos derivados de espécies de plantas foram os mais altos de entre todos os reinos taxonómicos (US\$151.68 mil milhões), embora a maioria dos custos não possam ser atribuídos a uma única espécie. Das espécies de ervas daninhas identificadas, as que resultaram em custos mais elevados foram o azevém anual (*Lolium rigidum*), a artemísia falsa (*Parthenium hysterophorus*) e a tasninha (*Senecio jacobaea*). As quatro classes taxonómicas mais caras foram: mamíferos (US\$48.63 mil milhões), insectos (US\$11.95 mil milhões), eudicotiledóneas (US\$4.10 mil milhões) e monocotiledóneas (US\$1.92 mil milhões). As três espécies mais caras corresponderam aos seguintes animais – gatos (*Felis catus*), coelhos (*Oryctolagus cuniculus*) e formigas de fogo (*Solenopsis invicta*). Cada Estado ou Território australiano teve um conjunto diferente de custos principais por espécie, mas a maioria (3–62%) dos custos foram associados com uma, ou até três, espécies por unidade política. A maioria (61%) dos custos registados foram aplicados a múltiplos ambientes e 73% do total de custos correspondeu a danos ou perdas diretas em comparação com apenas os custos de gestão; ambos os resultados refletindo a disponibilidade de dados. O aumento de espécies invasoras vai continuar a ter um custo substancial na economia Australiana, mas com um melhor plano de investimento, com padrões iguais para avaliações e registos e com intervenções coordenadas (incluindo extermínio), alguns destes custos podem ser substancialmente reduzidos.

### Abstract in Italian

**Stima dei costi economici riportati delle specie esotiche invasive in Australia.** Il lascito delle introduzioni intenzionali o accidentali di specie aliene invasive in Australia ha avuto un pesante conto, ciononostante, la quantificazione della magnitudine dei costi associati alla perdita diretta e ai danni, così come agli interventi di gestione, rimane elusiva. Questo perché l'attendibilità delle stime dei costi e i sottocampionamenti non sono stati determinati. Noi forniamo la prima analisi dettagliata dei costi riportati per l'economia australiana associati alle specie invasive dagli anni '60, basati sulla banca dati recentemente pubblicata InvaCost e informazioni supplementari, per un totale di 2078 voci di costo univoche. Dagli anni '60, l'Australia ha speso o ha subito perdite per un totale di almeno 298,58 miliardi di \$ americani (valore del 2017) o 389,59 miliardi di \$ australiani (tasso medio di conversione del 2017) per le specie invasive. Comunque, questa è una sottostima, dato che i costi aumentano all'aumentare del numero di stime, seguendo una legge di potenza. C'è un aumento medio nei costi totali di 1,8–6,3 volte per decennio dagli anni '70 ad oggi, producendo costi stimati a 6,09–57,91 miliardi di \$ americani all'anno (tutti i costi combinati) o 225,31 milioni–6,84 miliardi di \$ americani all'anno (solo costi osservati e con alta attendibilità). I costi derivanti dalle specie vegetali sono quelli più alti tra i regni (151,68 miliardi di \$ americani), sebbene la maggior parte dei costi non sia attribuibile a singole specie. Tra le specie infestanti identificate, le più costose sono il loglio rigido (*Lolium rigidum*), il partenio (*Parthenium hysterophorus*) e il senecione di S. Giacomo (*Senecio jacobaea*). Le quattro classi più costose sono: mammiferi (48,63 miliardi di \$ americani), insetti (11,95 miliardi di \$ americani), eudicotiledoni (4,10 miliardi di \$ americani) e monocotiledoni (1,92 miliardi di \$ americani). Le tre specie più costose sono animali: il gatto domestico (*Felis catus*), il coniglio selvatico europeo (*Oryctolagus cuniculus*) e la formica fuoco (*Solenopsis invicta*). Ogni Stato/territorio ha una diversa serie di costi principali per specie, ma la maggior parte dei costi (3–62%) deriva da una a tre specie per unità politica. La maggior parte dei costi riportati (61%) si applica a più ambienti e il 73% del totale riguarda il danno diretto o la perdita, piuttosto che i costi di sola gestione,

con entrambi questi risultati che riflettono la disponibilità di dati. Le crescenti incursioni delle specie invasive continueranno ad avere costi notevoli per l'economia australiana, ma con un migliore investimento, monitoraggio e rendicontazioni standardizzati e interventi coordinati (comprese le eradicazioni), alcuni di questi costi potrebbero essere sostanzialmente ridotti.

### Abstract in German

**Detaillierte Bewertung der gemeldeten wirtschaftlichen Kosten invasiver Arten in Australien.** Die absichtlichen und versehentlichen Einschleppungen invasiver gebietsfremder Arten in Australien haben einen hohen wirtschaftlichen Tribut gefordert, doch die Quantifizierung der Höhe der Kosten, die mit direkten Verlusten und Schäden sowie für Management-Interventionen verbunden sind, ist nach wie vor schwer fassbar. Dies liegt daran, dass die Zuverlässigkeit von Kostenschätzungen nicht ermittelt wurde. Diese erste detaillierte Analyse der gemeldeten Kosten für invasive Arten für die australische Wirtschaft basiert auf der Grundlage der kürzlich veröffentlichten InvaCost-Datenbank und zusätzlich bezogener Informationen und somit insgesamt 2078 eindeutigen Kosten-Einträgen. Seit den 1960er Jahren hat Australien Verluste in Höhe von mindestens 298,58 Mrd. USD (Wert 2017) oder 389,59 Mrd. AU \$ (durchschnittlicher Wechselkurs 2017) für invasive Arten verzeichnet. Dies ist jedoch eine Unterschätzung, da die Kosten steigen, wenn die Anzahl der Schätzungen nach dem Potenzgesetz zunimmt. Seit den 1970er Jahren haben sich die Gesamtkosten pro Jahrzehnt um das 1,8- bis 6,3-fache erhöht, was geschätzte Kosten von 6,09 bis 57,91 Milliarden US-Dollar (alle Kosten) oder 225,31 Millionen US-Dollar bis 6,84 Milliarden US-Dollar (empirisch beobachtete, zuverlässige Kosten) pro Jahr zur Folge hatte. Die Kosten für Pflanzenarten waren am höchsten (151,68 Mrd. USD), obwohl die meisten Kosten nicht auf einzelne Arten entfielen. Von den identifizierten Unkraut-Artigen Pflanzen waren die teuersten das einjährige Weidelgras (*Lolium Rigidum*), Parthenium (*Parthenium hysterophorus*) und das Kreuzkraut (*Senecio jacobaea*). Die vier teuersten Klassen waren Säugetiere (48,63 Milliarden US-Dollar), Insekten (11,95 Milliarden US-Dollar), Eudicots (4,10 Milliarden US-Dollar) und Monocots (1,92 Milliarden US-Dollar). Die drei teuersten Arten waren alle Tiere – Katzen (*Felis catus*), Kaninchen (*Oryctolagus cuniculus*) und die rote Feuerameise (*Solenopsis invicta*). Jeder Staat bzw. jedes Territorium hatte eine andere Reihe von Hauptkosten nach Arten, wobei die meisten (3–62%) Kosten von je ein bis drei Arten stammen. Die meisten (61%) der gemeldeten Kosten entfielen auf mehrere Umgebungen und 73% der Gesamtkosten betrafen direkte Schäden oder Verluste im Vergleich zu nur den Verwaltungskosten, wobei beide Ergebnisse die Verfügbarkeit von Daten widerspiegeln. Ansteigende Raten biologischer Invasionen werden weiterhin erhebliche Kosten für die australische Wirtschaft verursachen, aber durch bessere Investitionen, standardisierte Bewertungen und Berichterstattung sowie koordinierte Interventionen (einschließlich Ausrottungen) könnten einige dieser Kosten erheblich gesenkt werden.

### Abstract in Swedish

**Detaljerad bedömning av de rapporterade ekonomiska kostnaderna för invasiva arter i Australien.** Arvet efter avsiktlig och oavsiktlig introduktion av invasiva främmande arter till Australien har medfört en kraftig ekonomisk skada, men att kvantifiera storleken på kostnaderna förknippade med direkt förlust och skada, liksom för ledningsinsatser, är fortfarande svårgripbart. Detta beror på att tillförlitligheten hos kostnadsberäkningar och underprovtagning inte har fastställts. Vi tillhandahåller den första detaljerade analysen av de rapporterade kostnaderna för invasiva arter till den australiensiska ekonomin sedan 1960-talet, baserat på den nyligen publicerade InvaCost-databasen och kompletterande information, för totalt 2078 unika kostnadsuppgifter. Sedan 1960-talet har Australien spenderat eller drabbats av förluster på minst 298,58 miljarder USD (2017 års värde) eller 389,59 miljarder AUD (genomsnittlig växelkurs 2017) från invasiva arter. Detta är dock en underskattning med tanke på att kostnaderna stiger när antalet uppskattningar ökar enligt en potenslag. De totala kostnaderna per årtionde sedan 1970-talet fram till idag

ökade i genomsnitt 1,8–6,3 gånger vilket gav uppskattade kostnader på 6,09–57,91 miljarder USD/år (alla kostnader sammanlagt) eller 225,31 miljarder – 6,84 miljarder USD/år (observerade, endast mycket tillförlitliga kostnader). Kostnaderna för växtarter var de högsta bland rikena (151,68 miljarder USD), även om de flesta kostnaderna inte kan hänföras till enskilda arter. Av de identifierade ogräsarterna var de dyraste årlig Styvreppe (*Lolium rigidum*), Flikpartenium (*Parthenium hysterophorus*) och Stånds (*Senecio jacobaea*). De fyra dyraste klasserna var däggdjur (48,63 miljarder USD), insekter (11,95 miljarder USD), eudicots (4,10 miljarder USD) och monocots (1,92 miljarder USD). De tre dyraste arterna var alla djur – katter (*Felis catus*), kaniner (*Oryctolagus cuniculus*) och röda importerade eldmyror (*Solenopsis invicta*). Varje stat/territorium hade en skild uppsättning av kostnader per art, men de flesta (3–62%) av kostnaderna härrör från en till tre arter per politisk enhet. De flesta (61%) av de rapporterade kostnaderna tillämpades på flera miljöer och 73% av totalen avsåg direkt skada eller förlust jämfört med endast förvaltningskostnader, varvid båda dessa resultat återspeglar tillgängligheten av data. Stigande invasioner av invasiva arter kommer att fortsätta medföra betydande kostnader för den australiensiska ekonomin men med bättre investeringar, standardiserade bedömningar och rapportering och samordnade insatser (inklusive utrotningar) kan en del av dessa kostnader minskas avsevärt.

### Abstract in Greek

**Λεπτομερής εκτίμηση του καταγεγραμμένου οικονομικού κόστους των χωροκατακτητικών ειδών στην Αυστραλία.** Οι συνέπειες των τυχαίων και μη εισαγωγών χωροκατακτητικών ειδών στην Αυστραλία έχουν βαρύ οικονομικό τίμημα, αν και η ποσοτικοποίηση του κόστους, το οποίο σχετίζεται με την άμεση εξαφάνιση ή βλάβη, όπως και με τις διαχειριστικές παρεμβάσεις, παραμένει ελλιπής. Αυτό συμβαίνει διότι η αξιοπιστία των εκτιμήσεων κόστους και η μη-αντιπροσωπευτική δειγματοληψία δεν έχουν διερευνηθεί. Εδώ παρέχουμε την πρώτη λεπτομερή ανάλυση του αναφερόμενου οικονομικού αντίκτυπου που είχαν τα χωροκατακτητικά είδη στην οικονομία της Αυστραλίας από τη δεκαετία του 1960, βασιζόμενοι στην βάση δεδομένων Inva-Cost, η οποία δημοσιεύθηκε πρόσφατα, και άλλες συμπληρωματικές πληροφορίες, για ένα σύνολο 2078 μοναδικών καταχωρίσεων κόστους. Από τη δεκαετία του 1960, η Αυστραλία έχει δαπανήσει ή υπόκειται σε απώλειες συνολικού ύψους τουλάχιστον 298,58 δις δολαρίων (σε αξία 2017) ή 389,59 δις δολαρίων Αυστραλίας (μέσος δείκτης συναλλαγματικής ισοτιμίας του 2017) εξαιτίας των χωροκατακτητικών ειδών. Ωστόσο, πρόκειται σαφώς για υποτίμηση, δεδομένου ότι το κόστος αυξάνεται όσο αυξάνεται ο αριθμός των εκτιμήσεων ακολουθώντας κατανομή νόμου δύναμης. Από τη δεκαετία του 1970 μέχρι σήμερα, το συνολικό κόστος αυξήθηκε κατά μέσο όρο 1,8–6,3 φορές ανά δεκαετία, δημιουργώντας εκτιμώμενο οικονομικό αντίκτυπο της τάξης των 6,09–57,91 δις δολαρίων το χρόνο (για όλα τα κόσθη) ή 225,31 εκατομμυρίων–6,84 δις δολαρίων το χρόνο (συνυπολογίζονται μόνο στοιχεία κόστους υψηλής αξιοπιστίας που υλοποιήθηκαν). Το οικονομικό αντίκτυπο που προκύπτει από είδη φυτών ήταν το υψηλότερο συγκριτικά με τα υπόλοιπα βασίλεια (151,68 δις δολάρια), παρόλο που τα περισσότερα κόσθη δεν μπορούν να αποδοθούν σε ένα μόνο είδος. Από τα αναγνωρισμένα αγρωστώδη, αυτά με το υψηλότερο οικονομικό αντίκτυπο ήταν η Ήρα (*Lolium rigidum*), το Παρθένιο (*Parthenium hysterophorus*) και το Ιακώβαιο (*Senecio jacobaea*). Οι τέσσερις τάξεις με το υψηλότερο κόστος ήταν τα Θηλαστικά (48,63 δις δολάρια), τα Έντομα (11,95 δις δολάρια), τα Ευδικοτυλήθωνα φυτά (4,10 δις δολάρια) και τα Μονοκοτυλήθωνα φυτά (1,92 δις δολάρια). Τα τρία είδη με το μεγαλύτερο οικονομικό αντίκτυπο ήταν όλα ζώα — γάτες (*Felis catus*), κουνέλια (*Oryctolagus cuniculus*) και Αμερικάνικα κόκκινα μυρμηγκία (*Solenopsis invicta*). Η σύνθεση των κύριων στοιχείων κόστους ανά είδος ήταν διαφορετική για κάθε πολιτεία/επιπράτεια, με τα περισσότερα κόσθη (3–62%) ωστόσο να προέρχονται από ένα έως τρία είδη ανά διοικητική μονάδα. Η πλειονότητα (61%) των καταγεγραμμένων στοιχείων κόστους αφορούσε σε πολλαπλά περιβάλλοντα και 73% του συνόλου αυτών αφορούσε σε άμεση βλάβη ή εξαφάνιση, σε σύγκριση με το κόστος διαχείρισης αποκλειστικά, με τα δύο αυτά αποτελέσματα να αντανακλούν την διαθεσιμότητα των δεδομένων. Η αύξηση στην εισαγωγή χωροκατακτητικών ειδών θα συνεχίσει να έχει σημαντικό οικονομικό αντίκτυπο για την Αυστραλιανή οικονομία, αλλά με καλύτερες επενδύσεις, τυποποιημένες αξιολογήσεις και

αναφορές, καθώς και με συντονισμένες παρεμβάσεις (συμπεριλαμβανομένης της εξολόθρευσης), μέρος του κόστους μπορεί να μειωθεί σημαντικά.

### Abstract in Japanese

#### オーストラリアにおける侵入種の経済的影響の包括的な評価

オーストラリアへの侵略的外来種の故意かつ偶発的な導入の余波は多大な経済的犠牲をもたらしたが、直接的な損失と被害、および管理介入に関連する経済的影響（コスト）の大きさを定量化することは、とらえどころのないままである。これは、推定値とアンダーサンプリングの信頼性が決定されていないためである。最近公開されたInvaCostデータベースと補足情報に基づいて、1960年代以降、オーストラリア経済への侵入種に関連して報告されたコストの詳細な分析をはじめ提供し、合計2078の固有のコストエントリを提供することができた。1960年代以降、オーストラリアは、侵入種から少なくとも合計2985.8億米ドル（2017年の価値）あるいは3895.9億豪ドル（2017年の平均為替レート）の損失を費やした。ただし、べき法則に従って見積もりの数が増えるとコストが上がることを考えると、これは過小評価である。1970年代から現在までの10年間の総コストは平均1.8~6.3倍に増加し、推定コストは1年目で60億9千万~57.9億ドル（合計）、1年目で2億2,531万~68.4億ドルになった（観察された、信頼性の高いコストのみ）。植物種から生じる費用は、植物界と動物界の間で最も高かった（1516.8億米ドル）が、費用のほとんどは単一種に起因するものではなかった。同定された雑草種の中で、最も高価なのは、毎年恒例のライグラス（*Lolium rigidum*）、パルテニウム（*Parthenium hysterophorus*）、およびラグワート（*Senecio jacobaea*）だった。最も費用のかかる4つのクラスは、哺乳類（486.3億米ドル）、昆虫（119.5億米ドル）、真正双子類（41.0億米ドル）、単子葉植物（19億2000万米ドル）だった。最も高価な3種は、猫（*Felis catus*）、ウサギ（*Oryctolagus cuniculus*）、ヒアリ（*Solenopsis invicta*）のすべての動物でした。各州/準州には、種ごとに異なる一連の主要なコストがあったが、ほとんど（3~62%）のコストは、政治単位ごとに1~3種に由来していた。報告されたコストのほとんど（61%）は複数の環境に適用され、全体の73%は管理コストのみと比較して直接的な損傷または損失に関連しており、これらの調査結果は両方ともデータの可用性を反映している。侵入種の侵入の増加は、オーストラリア経済にとって引き続きかなりのコストがかかるが、より良い投資、標準化された評価と報告、および調整された介入（根絶を含む）により、これらのコストの一部は大幅に削減される可能性がある。

### Abstract in Korean

#### 오스트레일리아의 외래침입종의 경제적 비용에 대한 상세 평가

의도적이거나 우연히 호주로 유입된 외래 침입종은 막대한 경제적 손실을 발생시켰지만, 외래종의 유입으로 인한 직접적인 손실 및 피해와 관련된 직접적인 비용뿐만 아니라 관리 비용 등의 규모는 여전히 수치화되지 못하고 있다. 이는 비용 추정치 및 과소 표집의 신뢰성이 부족하기 때문이다. 우리는 총 2078개의 고유 비용 항목에 대해 최근 발표된 InvaCost 데이터베이스를 기반으로 1960년대 이후 오스트레일리아로 유입된 외래 침입종의 경제 비용에 대한 상세 분석을 진행하였다. 1960년대 이후 오스트레일리아는 외래 침입종으로 인하여 최소 2985억 8천만 달러 (2017년 미화 가치 기준) 또는 3895억 9천만 달러 (2017년 평균 환율 적용한 오스트레일리아화 기준)의 경제적 손실을 보았다. 그러나 추정치의 수가 증가함에 따라 비용이 증가한다는 역 법칙을 고려하였을 때 이는 과소평가되었다고 볼 수 있다. 1970년대 이후 현재까지 매 10년간 총비용은 1.8 - 6.3배 증가하였으며, 추정비용은 연간 미화 609 - 579억 (모든 비용을 포함하였을 경우) 혹은 미화 2억 253만 1천 - 68억 4천만 (신뢰성이 높은 알려진 비용만 포함한 경우) 달러 수준이다. 연구에 포함된 계 중 식물 중에서 발생한 비용이 가장 높았으나 (미화 1516억 8천만 달러) 단일종 큰 집중적으로 비용을 발생시키지는 않았다. 확인된 잡초종

중에서 가장 큰 비용을 발생시킨 종은 호밀 (*Lolium rigidum*), 파르테눔 (*Parthenium hysterophorus*) and 래그워트 (*Senecio jacobaea*) 등이었다. 강 분류 별로 포유류 (미화 486억 3000만 달러), 곤충 (119억 5천만 달러), 진정쌍떡잎식물 (미화 41억 1천만 달러), 외떡잎식물 (미화 19억 2천만 달러) 등이 가장 큰 비용을 발생시켰다. 종 분류 별로 가장 큰 비용을 발생시킨 종은 고양이 (*Felis catus*), 토끼 (*Oryctolagus cuniculus*), 붉은 불개미 (*Solenopsis invicta*) 등의 동물들이었다. 각각의 주 별로 비용을 발생시킨 주요 종이 다르지만, 대부분 (3 - 62%)의 비용은 주별로 1 - 3개의 종에 의해서 발생하였다. 보고된 비용의 대부분 (61%)은 다양한 환경에 적용되었고, 전체 비용의 73%는 관리 비용보다는 직접적인 손실에 관련되어 있으며, 두 결과 모두 데이터의 가용성을 반영한다. 외래 침입종의 유입 증가는 오스트레일리아 경제에 상당한 비용을 부담시킬 것이다. 그러나 적절한 투자와, 표준화된 평가 및 보고 방법, 조직적인 개입 (퇴치 포함)은 이러한 비용을 상당히 감수할 수 있을 것이다.

### Abstract in Russian

**Подробная оценка фактических экономических потерь от инвазионных видов в Австралии.** Наследие осознанной и случайной интродукции инвазионных чужеродных видов в Австралии привело к огромным экономическим потерям, однако же количественные оценки величин экономических потерь, связанных с прямым ущербом, а также с расходами на контроль инвайдеров все еще единичны. Это имеет отношение в том числе и к проблеме надежности оценок и их недостаточности. Мы предоставляем первый подробный анализ фактических экономических потерь от инвазионных видов для австралийской экономики начиная с 1960-х гг., проведенный на основе данных из недавно опубликованной базы данных InvaCost и дополнительной информации; всего было проанализировано 2078 позиций убытков. С 1960-х гг. фактические и прогнозные убытки от инвазионных видов в Австралии в совокупности составили около 298,58 млрд долларов США (по курсу валюты на 2017 г.), или 389,59 млрд австралийских долларов (по среднему обменному курсу на 2017 г.). Однако это заниженная оценка, учитывая тот факт, что величина потерь растет с увеличением числа оценок согласно степенному закону. С 1970-х гг. по настоящее время общие потери увеличивались в среднем в 1,8–6,3 раза за десятилетие, в результате чего предполагаемые потери составили 6,09–57,91 млрд долларов США в год<sup>-1</sup> (все потери вместе взятые) или от 225,31 млн до 6,84 млрд долларов США в год<sup>-1</sup> (только фактические высоконадежные оценки). Потери, связанные с чужеродными растениями, были самыми высокими в сравнении с таковыми в разных таксономических царствах (151,68 млрд долларов США), вместе с тем значительная часть экономических потерь не относилась к одному конкретному биологическому виду. Среди сорных растений наибольшие убытки были связаны с райграсом однолетним (*Lolium rigidum*), партенией (*Parthenium hysterophorus*) и крестовником луговым (*Senecio jacobaea*). Значительные потери были вызваны инвазиями представителей четырех таксономических классов: млекопитающих (48,63 млрд долларов США), насекомых (11,95 млрд долларов США), эвдикотов (4,10 млрд долларов США) и однодольных растений (1,92 млрд долларов США). Среди животных наибольший ущерб был отмечен от кошек (*Felis catus*), кроликов (*Oryctolagus cuniculus*) и красных огненных муравьев (*Solenopsis invicta*). Каждый штат или территория характеризовался разными типами потерь от видов-инвайдеров, но большинство потерь (3–62%) приходилось на 1–3 вида-инвайдера на административно-территориальную единицу. Большая часть (61%) экономических потерь была задокументирована для нескольких сред обитания, а 73% от общей суммы убытков относились к прямым потерям или тратам на контроль, что обусловлено наличием таких оценок. Рост инвазий будет продолжать приносить существенные расходы экономике Австралии, но при более эффективных инвестициях, стандартизированных оценках и отчетности, а также скоординированных действиях (включая искоренение видов-инвайдеров) некоторые из этих затрат могут быть существенно сокращены.

**Abstract in Arabic**

ايلارتسا يف فيزاغلا عون اول ان ع نل عمل ا فيداصتقال فيل الكتلل يل ي صفت مي ي ق ت  
 ىل ا يدا ايلارتسا ىل ا يضر ع ل ا و ا ان م تم ع ت م ل ا ءاوس ق ب ي ر ع ل ا فيزاغلا عون ال ا ل ا خ د ا يدا :صل خست م ل  
 رارض ال او رئاس خ ل اب ق ط ب ت م ل ا فيل الكتلل م ح د د ي د ح ت ل ا ز ي الف ل ك ل ذ ع م و ، ق ظ ه ا ب فيداصتقا فيل الكتل  
 تاري د ق ت ق د د ي د ح ت م د ع ىل ا ل ك ل ذ ي ف ب ب س ل ا د و ع ي و . ق ي ق ح ت ل ا ق د ي ع ب في ر ا د ا ل ا ت ا ل خ د ت ل ا و ق ر ش ا ب م ل ا  
 ل ي ل ح ت ل و ا م ي ي ق ت ل ا ا ذ ه ي ف م د ق ن و . ع ا و ن ال ا ذ ه ن م ت ا ن ي ع ل ا ذ خ ا ي ف ص ر ق ن ل ا ل ك ل ذ ك و فيداصتقال ا ق ف ل ك ت ل  
 فيدا ي م ل ا ت ا ن ي ت س ل ا ن م ي ل ا ر ت س ل ا ا د ا ص ت ق ا ل ل فيزاغلا عون ال اب ق ط ب ت م ل ا و ان ع ن ل عمل ا فيل الكتلل  
 2078 ي ل م ا ج ا ب ا ه ي ف ق ي ل م ل ك ت ل ا ت ا م و ل عمل ا و ا ر خ و م ق ر و ش ن م ل ا InvaCost ت ا ن ا ي ب ق د ع ا ق ى ل ع ا ن ب ل ك ل ذ و  
 فيزاغلا عون ال ا ذ ه ن م فيدا ي م ل ا ت ا ن ي ت س ل ا ن م ا ي ل ا ر ت س ل ا رئاس خ م و م ج م ت غ ل ب ت ش ي ح . د ر ف ت م ل خ م  
 389.59 ل د ا ع ي م ا و ه و 2017 م ا ع ت ا ن ا ي ب ى ل ع ا ن ب ل ق ال ا ى ل ع ي ك ي ر م ر الود ر ا ي ل م 298.58 ب ر ا ق ي ا م  
 ن ال ا ر ظ ن ع ق ا و ل ا ن م ل ق ا م ق ر ل ا ا ذ ه د ع ي ل ك ل ذ ع م و . م ا ع ل ا س ف ن ل ف ر ص ل ا ر ع س ب س ح ل ك ل ذ و ي ل ا ر ت س ل ا ر الود  
 ط س و ت م ن ا ك ت ش ي ح . في م س ر ل ا ن ي ن و ا ق ل ل ا ق ب ط ت ا ر ي د ق ت ل ا د د ع ق د ا ي ز ع م ع ف ت ر ت فيداصتقال ا فيل الكتلل  
 ى ت و فيدا ي م ل ا ت ا ن ي ن ي ع ب س ل ا ن م د ق ع ل ك ل فيل الكتلل ا ي ل م ا ج ا ي ف 6.3 ىل ا 1.8 ن ي ب ا م ح و ا ر ت ي ق د ا ي ز ل ا  
 ر الود ر ا ي ل م 57.91 ىل ا 6.09 ن ي ب ا م ح و ا ر ت ت في ر ي د ق ت فيل الكتلل د ي د ح ت ىل ا يدا ا م ، ر ض ا ح ل ا ت ق و ل ا  
 ا ي و ن س ي ك ي ر م ر الود ر ا ي ل م 6.84 - ي ك ي ر م ر الود ن و ي ل م 225.31 و ا ( فيل الكتلل ق ل م ج ) ا ي و ن س ي ك ي ر م ر  
 ن م ى ل ع ل ا ي ه فيزاغلا في ت ا ب ن ل ا ع ا و ن ال ا ن ع في ش ا ن ل ا فيل الكتلل ت ن ا ك . ( في ا غ ل ق ق و ش و م فيل الكتل ، ق ظ و ح ل م )  
 م ط ع م ن ا ن م م غ ر ل ا ب ي ك ي ر م ر الود ر ا ي ل م 151.68 ن م ب ر ا ق ي ا م ق ف ل ك ت ل ا ت غ ل ب ت ش ي ح ى ر خ ال ا ع ا و ن ال ا ن ي ب  
 ت ا ب ن ا د ي د ح ت م ت ي ت ل ا ب ا ش ع ل ا ع ا و ن ا ن ي ب ن م ق ف ل ك ت ى ل ع ال ا ت ن ا ك و . د د ج م ع و ن ىل ا ز غ ت م ل فيل الكتلل  
 ( *Senecio jacobaea* ) خ ي ش ل ا ق ر و ز و ( *Parthenium hysterophorus* ) م و ي ن ي ث ر ا ب ل ا و ( *Lolium rigidum* ) ي و ن س ل ا ن ش خ ل ا ن و ز ل ا  
 ( ي ك ي ر م ر الود ر ا ي ل م 48.63 ) ت ا ي ي د ت ل ا ل م ش ت ق ف ل ك ت ر ت ك ال ا ع ب ر ال ا ت ا ي ن ف ل ا ت ن ا ك ا م ك . ( *Felicia jacobaea* )  
 ( ي ك ي ر م ر الود ر ا ي ل م 4.10 ) ق ي ق ي ح ل ق ق ل ف ل ا ت ا ي ن ا ن ش و ( ي ك ي ر م ر الود ر ا ي ل م 11.95 ) ت ا ر ش ح ل ا و  
 ع ي م ج ل م ش ت ق ف ل ك ت ر ت ك ال ا ق ت ا ل ا ع ا و ن ال ا ت ن ا ك و . ( ي ك ي ر م ر الود ر ا ي ل م 1.92 ) ق ق ل ف ل ا ت ا ي د ا ح ا و  
 د ر و ت س م ل ا ي ر ا ن ل ا م ح ال ا ل م ن ل ا و ( *Oryctolagus cuniculus* ) ب ن ا ر ال ا و ( *Felis catus* ) ال ش م ط ط ل ك ت ا ن ا و ي ح ل ا  
 ع ا و ن ال ا ب س ح ق ر ي ب ل ك ل ا فيل الكتلل ن م ق ف ل ت خ م ع و م ج م م ي ل ق ا و ا ق ي ا ل و ل ك ل ن ا ك ا م ك . ( *Solenopsis invicta* )  
 ل ك ل ع ا و ن ا ق ت ا ل ت ىل ا ع و ن ن م ق ت ق ت ش ا ( 26% - 3 ) فيل الكتلل م ط ع م ن ك ل و م ي ل ق ال ا و ا ق ي ا ل و ل ا ذ ه ي ف ق د و ج و م ل  
 ق ل ع ت ي ا م ن ي ب ق د ع ت م ت ا ي ي ب ى ل ع ا ق ي ب ط ت م ت ( 61% ) ا ن ع غ ل ب ي ت ل ا فيل الكتلل م ط ع م . في س ا ي س ق د ح و  
 ط ق ف في ر ا د ا ل ا فيل الكتلل ا ق ن ر ا ق م ق ر ش ا ب م ل ا ق ر ا س خ ل ا و ا ر ر ض ا ب ت ا غ ل ب ل ا ي ل م ا ج ا ن م 73% ب ر ا ق ي ا م  
 د ي ا ز ت م ل ك ش ب فيزاغلا عون ال ا ق د ا ي ز م ت س ت س و . ت ا ن ا ي ب ل ا ر ف ا و ت ا ن ا س ك ع ت ن ي ت ج ي ت ن ل ا ن ي ت ا ه ل ك و  
 ذ ه ض ع ب ض ي ف ي ف خ ن ك م ي ن ك ل و . ق ر ي ب ك فيل الكتلل ا ي ل ا ر ت س ل ا ا د ا ص ت ق ا ل ا ت م ح ي س ا م ل ب ق ت س م ل ا ي ف  
 ق ف ا ض ا ل ا ب فيل الكتلل ا ر ا ت ا ل ل م ي ي ق ت ل ا د ي ح و ت و ا م ن ش ت س ل ا ن ي س ح ت ل ا ل خ ن م ر ي ب ك ل ك ش ب فيل الكتلل  
 ر م ل ا م ز ل ا ن ا ل ا ص ئ ت س ل ا ل ك ل ذ ي ف ا م ب ت ا ل خ د ت ل ا ق ي س ن ت ىل ا

**Abstract in Farsi**

ايلارتسا رد ي م و ب ر ي غ ي ا ه ن و گ ي د ا ص ت ق ا ن ا ي ز ش ر ا ز گ ي ب ا ي ز ر ا  
 م ت ش ا د ر ب ر د ي د ا ص ت ق ا ن ي گ ن س ا ه ا د م ا ي پ ا ي ل ا ر ت س ا ه ب ي م و ب ر ي غ ي ا ه ن و گ ي د ا ص ت و ي د م ع د و ر و  
 ر د ا م . ت س ا ر ا و ش د ن ا ( ل ر ت ن ك ) ا ر ح ب ت ي ر ي د م ن ي ن چ م ه و ن ا ي ز و ر ر ض ه ن ي ز ه د ر و ا ر ب ، د و ج ن ي ا ب ت س ا  
 ۱۹۶۰ ل ا س ز ا ي م و ب ر ي غ ي ا ه ن و گ د و ر و ز ا ه د ش ش ر ا ز گ ي د ا ص ت ق ا ي ا ه ن ي ز ه ر ا ب ن ي ل و ا ي ا ر ب ط ا ق م ن ي ا  
 ي س ر ر ب ( د ش ا ب ي م ه ع ل ا ط م ۲۰۷۸ د ا د ع ت ل م ا ش ه ك ) ت س ك و ن ي ا ي ت ا ع ا ل ا ط ا ع ب ن م س ا س ا ر ب ا ر ا ي ل ا ر ت س ا ه ب  
 ۲۹۸.۵۸ ل ق ا د ا ح ل د ا ع م ى ل ا م ر ر ض ل م ح ت م ي م و ب ر ي غ ي ا ه ن و گ ل ي ل د ه ب ر و ش ك ن ي ا ، ۱۹۶۰ ل ا س ز ا . م ي د ر ك  
 . ت س ا ( ه د ش ) ۲۰۱۷ ل ا س ر د ر ا ل د خ ر ن ب ا س ت ح ا ( ه ب ا ي ل ا ر ت س ا ر ا ل د ن و ي ل ي ب ۳۸۹.۵۹ ا ك ي ر م ر ا ل د ن و ي ل ي ب  
 ن ي ر ت ا ل ا ب . ت س ا ه د ش ر ب ا ر ب ۶.۳ ا ت ۱.۸ ط س و ت م ر و ط ه ا ه ن ي ز ه ن ا ز ي م ه د ر د ، ن و ن ك ا ت ۱۹۷۰ ل ا س ز ا  
 ص ت خ م ه ج ر گ ا ، ) ا ك ي ر م ر ا ل د ن و ي ل ي ب ۱۵۱.۶۸ ( ت س ا ي ه ا ي گ ي ا ه ن و گ ه ب ط و ب ر م ا ه ل س ل س ن ا ي م ر د ن ي ز ه  
 ، س ر گ ي ا ر ل م ا ش ا م ن ي ر ت ه ن ي ز ه ر ب ، ه د ش ي س ا ن ا ش ي ف ل ع ي ا ه ن و گ ن ا ي م ز ا . د ش ا ب ي م ن ي ص ا خ ه ن و گ ه ب  
 ، ) ا ك ي ر م ر ا ل د ن و ي ل ي ب ۴۸.۶۳ ( ن ر ا د ن ا ت س پ ل م ا ش ه ن ي ز ه ر ب ، م د ر ر ا ه ج . د ن ا ، ه د و ب ت ر و و گ ا ر و م و ي ن ت ر ا ب  
 ۱.۹۲ ) ( ا ه ي ا ه ي ل ك ت و ) ا ك ي ر م ر ا ل د ن و ي ل ي ب ۴.۱۰ ( ا ه ي ا ه ي ل و د ، ) ا ك ي ر م ر ا ل د ن و ي ل ي ب ۱۱.۹۵ ( ت ا ر ش ح  
 ا م ش و گ ر خ ، ا ه ب ر گ - د ن ا ، ه د و ب ت ا ن ا و ي ح ز ا ي گ م ه ن ي ز ه ر ب ، ن و گ م س . ت س ا ، ه د و ب ) ا ك ي ر م ر ا ل د ن و ي ل ي ب  
 ۷۳ و ا ه گ ت س ي ز د ن چ ه ب ط و ب ر م ا ه ن ي ز ه ل ك د ص ر د ۶۱ ه ك ت س ا م د ا د ن ا ش ن د ه ا و ش . ي م و ب ر ي غ ز م ر ق ي ا ه ه ج ر و م و

دی‌کات و) دش‌اب یم‌ن نارحب تی‌ری‌دم‌ن‌یزه لام‌اش رام‌آ نی‌ا( دش‌اب‌یم‌ن‌ایز و ررض‌ب‌ب‌طوبرم‌اه‌ن‌یزه‌د‌ص‌ر‌ر‌د  
 دش‌ن‌ت‌ب‌ت‌د‌ان‌س‌ا‌س‌ا‌س‌ا‌ر‌ب‌ن‌آ‌ری‌ی‌غ‌ت‌ن‌ا‌ک‌م‌ا‌و‌ه‌د‌وب‌ه‌د‌ش‌ت‌ب‌ت‌د‌ان‌س‌ا‌س‌ا‌ر‌ب‌م‌ا‌ق‌ر‌ا‌ن‌آ‌م‌ک‌م‌ی‌ن‌ک‌ی‌م  
 ی‌اه‌ن‌و‌گ‌ی‌ف‌د‌ا‌ص‌ت‌و‌ی‌د‌م‌ع‌د‌و‌ر‌و‌ر‌ط‌ا‌خ‌م‌ب‌ای‌ل‌ا‌ر‌ت‌س‌ا‌ر‌و‌ش‌ک‌م‌ب‌ی‌د‌ا‌ص‌ت‌ق‌ا‌ن‌ایز‌و‌ر‌رض‌ل‌ی‌م‌ح‌ت‌.‌د‌ر‌اد‌د‌و‌ج‌و  
 داد‌ش‌ه‌ا‌ک‌ا‌ر‌اه‌ن‌یزه‌ز‌ا‌ی‌خ‌ر‌ب‌ن‌ا‌و‌ت‌ی‌م‌ر‌ت‌م‌ب‌ی‌ر‌ا‌ذ‌گ‌ه‌ی‌ا‌م‌ر‌س‌ا‌ب‌ی‌ل‌و‌،‌ت‌ش‌اد‌د‌ه‌ا‌و‌خ‌م‌ا‌د‌ا‌ی‌م‌و‌ب‌ر‌ی‌غ

### Abstract in Czech

**Podrobné zhodnocení vykázaných ekonomických nákladů způsobených invazivními druhy v Australii.** Úmyslné i náhodné zavlečení nepůvodních invazních druhů do Austrálie si vyžádalo značné ekonomické náklady. Výše těchto nákladů ve vztahu ke způsobeným škodám a managementu těchto druhů je však do značné míry neznámá. Hlavním důvodem je nedostatečná dostupnost a spolehlivost takovýchto odhadů. Tato studie představuje první podrobnou analýzu vykázaných nákladů způsobených invazivními druhy australskému hospodářství od 60. let minulého století. Studie vychází z nedávno zveřejněné databáze InvaCost a doplňujících zdrojů, jež celkem podchycují 2078 jedinečných záznamů takovýchto nákladů. Od šedesátých let minulého století již vynaložila Austrálie za dopady invazních druhů nejméně 298,6 miliardy amerických dolarů (hodnota pro rok 2017). Tyto náklady jsou však podhodnoceny, jelikož jejich úroveň roste s počtem dostupných odhadů. Od 70. let do současnosti došlo v průměru k 1,8–6,3násobnému nárůstu celkových nákladů za desetiletí, což vedlo k odhadovaným nákladům 6,09–57,91 miliardy amerických dolarů ročně (souhrn všech nákladů) nebo 225,3 milionu až 6,84 miliard amerických dolarů ročně za pozorované, vysoce spolehlivě prokázané náklady. Nejvyšší náklady byly na invazní rostliny (151,7 miliard amerických dolarů), ačkoli jejich většinu nelze přiřít jednomu druhu. Nejvýznamnějšími byli jílky tuhé (*Lolium rigidum*), sambaba obecná (*Parthenium hysterophorus*) a starček přímětník (*Senecio jacobaea*). Čtyřmi nejnákladnějšími třídami byli savci (48,63 miliard amerických dolarů), hmyz (11,95 miliard amerických dolarů), dvouděložné (4,10 miliard amerických dolarů) a jednoděložné rostliny (1,92 miliard amerických dolarů). Třemi nejnákladnější živočichy byla kočka domácí (*Felis catus*), králík divoký (*Oryctolagus cuniculus*) a mravenec (*Solenopsis invicta*). Každý stát/teritorium měl jinou skupinu nejnákladnějších druhů, ale většina (3–62%) nákladů vždy pocházela od jednoho až tří druhů. Většina (61%) vykázaných nákladů se vztahovala k více typům prostředí a 73% z této částky se týkalo přímých škod, na rozdíl od nákladů na management těchto druhů, jak ukazují dostupná data. Počet invazních druhů se bude zvyšovat, což bude mít za následek rostoucí náklady pro australské hospodářství, avšak lepšími investicemi, standardizovaným hodnocením i vykazováním a koordinovanými zásahy (včetně eradikací) lze některé z těchto nákladů podstatně snížit.

### Abstract in Polish

**Kompleksowa ocena kosztów ekonomicznych gatunków inwazyjnych w Australii.** Dziedzictwo celowego i przypadkowego wprowadzenia inwazyjnych gatunków obcych do Australii miało ogromny wpływ na gospodarkę, jakkolwiek wycena wielkości kosztów związanych z bezpośrednimi stratami i szkodami oraz interwencją w zakresie zarządzania, pozostaje nieuchwytna. Wynika to z tego, że nie określono wiarygodności szacunków kosztów i niedostatecznego pobierania próbek. Dostarczamy pierwszej szczegółowej analizy kosztów poniesionych przez australijską gospodarkę, związanych z gatunkami inwazyjnymi, zgłoszonych od 1960 roku. Analiza ta została oparta o niedawno opublikowaną bazę danych InvaCost oraz informacje uzupełniające, w sumie 2078 indywidualnych wpisów kosztów. Od 1960 roku Australia poniosła koszty i straty z powodu gatunków inwazyjnych w łącznej wysokości co najmniej 298,58 mld USD (wartość z 2017 r.), co stanowi równowartość 389,59 mld AUD (średni kurs wymiany z 2017 r.). Jest to jednak niedoszacowanie, biorąc pod uwagę, że koszty się potęgują wraz ze wzrostem liczby szacunków. Od lat 1970-tych do chwili obecnej nastąpił średnio 1,8–6,3-krotny wzrost całkowitych kosztów na dekadę, co oznacza wzrost szacowanych kosztów w wysokości 6,09–57,91 mld USD rocznie (wszystkie koszty łącznie) lub 225,31 mln–6,84 mld USD rocznie (dotyczące tylko bardzo wiarygodnych kosztów). Koszty związane z gatunkami roślinnymi były najwyższe wśród królestw (151,68 mld USD), chociaż

większość kosztów nie była przypisywana pojedynczym gatunkom. Ze zidentyfikowanych gatunków chwastów najwyższych kosztów przysporzyły życica sztywna (*Lolium rigidum*), partenium ambrozjowate (*Parthenium hysterophorus*) i starzec jakubek (*Senecio jacobaea*). Czterema klasami powodującymi najwyższe koszty były ssaki (48,63 mld USD), owady (11,95 mld USD), rośliny dwuliścienne (4,10 mld USD) i jednoliścienne (1,92 mld USD). Trzema gatunkami powodującymi najwyższe koszty były zwierzęta – koty (*Felis catus*), króliki (*Oryctolagus cuniculus*) i mrówki ogniste (*Solenopsis invicta*). Każdy stan/terytorium miał inny zestaw głównych kosztów według gatunków, ale większość tych kosztów (3–62%) pochodziła z jednego do trzech gatunków na jednostkę polityczną. Najwięcej (61%) zgłoszonych kosztów odnosiło się do wielu środowisk, a 73% całkowitej kwoty dotyczyło bezpośrednich szkód lub strat w porównaniu tylko z kosztami zarządzania, przy czym oba te ustalenia odzwierciedlają dostępność danych. Wzrost ilości gatunków inwazyjnych nadal będzie się wiązał ze znacznymi kosztami dla australijskiej gospodarki, ale dzięki zastosowaniu lepszych inwestycji, znormalizowanych ocen i sprawozdawczości oraz skoordynowaniu interwencji (w tym likwidacji), niektóre z tych kosztów mogłyby zostać znacznie zmniejszone.

### Abstract in Bosnian/Croatian

#### Detaljna procjena prijavljenih ekonomskih troškova invazivnih životinjski i biljni vrsta u Australiji.

Nasljedje namjernog i slučajnog unošenja invazivnih stranih životinjski i biljni vrsta u Australiju imalo je pozamašan ekonomski utjecaj, ali kvantificirajući veličinu troškova povezanih sa izravnim gubicima i štetom, kao troskove za upravljanje intervencije i dalje je nedostižno. Razlog ovoga he zato sto pouzdanost procjena troškova i nedovoljno uzorkovanje nisu utvrđene i standarizovane. Ovdje dajemo prvu detaljnu analizu prijavljenih troškova povezanih s invazivnim životinjskim i biljnim vrstama za Australsko gospodarstvo od 1960-ih, na temelju nedavno objavljene baze podataka InvaCost i dodatnih podataka, za ukupno 2078 jedinstvenih unosa troškova. Od šezdesetih godina Australija je od invazivnih životinjskin i biljni vrsta potrošila ili pretrpjela gubitke u ukupnom iznosu od najmanje 298,58 milijardi američkih dolara (vrijednost 2017.) ili 389,59 milijardi američkih dolara (prosječni tečaj 2017.). Međutim, ovo je znacajno podcijenjeno s obzirom na to da troškovi rastu kako se broj procjena povećava slijedeći zakonske promjene. Ukupni troškovi po desetljeću od 1970-ih do danas u prosjeku su porasli za 1,8–6,3 puta, što je prouzrokovalo procijenjene troskove od 6,09–57,91 milijardi USD<sup>1</sup> (svi troškovi zajedno) ili 225,31 milijuna– 6,84 milijarde USD<sup>1</sup> (uočeno, samo vrlo pouzdani troškovi). Troškovi biljnih vrsta bili su najveći među kraljevstvima (151,68 milijardi USD), iako se većina troškova nije pripisala jednoj vrsti biljki. Od identificiranih korovitih vrsta biljki najskuplji su bili jednogodišnji ljulj (*Lolium rigidum*), partenij (*Parthenium hysterophorus*) i krpa (*Senecio jacobaea*). Četiri najskuplje klase bili su sisavci (48,63 milijarde USD), insekti (11,95 milijardi USD), eudikoti (4,10 milijardi USD) i monokoti (1,92 milijarde USD). Tri najskuplje vrste bile su sve životinje – mačke (*Felis catus*), zečevi (*Oryctolagus cuniculus*) i crveni uvezeni vatreni mravi (*Solenopsis invicta*). Svaka država / teritorij imala je različit skup glavnih troškova po vrstama, ali s većinom (3–62%) troškova koji proizlaze iz jedne do tri vrste po političkoj jedinici. Većina (61%) prijavljenih troškova odnosila se na više okruženja, a 73% ukupnih troškova odnosilo se na izravnu štetu ili gubitak u usporedbi samo s troškovima upravljanja, s tim da oba ova otkrića direktno ovise o dostupnosti podataka. Rastući napadi invazivnih životinjski i biljni vrsta i dalje će imati značajne troskove za Australsko gospodarstvo, ali boljim ulaganjem, standardiziranim procjenama i izvješćivanjem te koordiniranim intervencijama (uključujući iskorjenjivanje), neki od tih troškova mogli bi se znatno smanjiti u budućnosti.

### Abstract in Punjabi

ਆਸਟਰੇਲੀਆ ਵੱਚਿ ਧਾੜਵੀ ਪ੍ਰਜਾਤੀਆਂ ਦੀਆਂ ਰਪਿਰਟ ਕੀਤੀਆਂ ਆਰਥਕਿ ਕੀਮਤਾਂ ਦਾ ਵਸਿਤਰਤਿ ਮੁਲਾਂਕਣ ਆਸਟਰੇਲੀਆ ਵੱਚਿ ਗੈਰ-ਮੂਲ ਪਰਦੇਸੀ ਜਾਤੀਆਂ ਦੀ ਜਾਣੇ-ਅਣਜਾਣੇ ਵੱਚਿ ਕੀਤੀ ਗਈ ਅਸਥਾਪਨਾ ਨਾਲ ਭਾਰੀ ਆਰਥਕਿ ਘਾਟਾ ਪਿਆ ਹੈ, ਫਰਿ ਵੀ ਸੌਧਿ ਘਾਟੇ ਅਤੇ ਨੁਕਸਾਨ ਦੇ ਨਾਲ-ਨਾਲ ਪ੍ਰਬੰਧਨ ਦੇ ਦਖਲਅੰਦਾਜ਼ੀ ਨਾਲ ਜੁੜੇ ਖਰਚਿਆਂ ਦੀ ਵਆਖਿਆ ਮੁਸ਼ਕਲ ਹੈ। ਅਜੇਹਾ ਇਸ ਲਈ ਹੈ ਕਉਕਿ ਲਾਗਤ ਦੇ ਅਨੁਮਾਨਾਂ ਅਤੇ ਘੱਟ ਨਮੂਨੇ ਲੈਣ ਦੀ ਭਰੋਸੇਯੋਗਤਾ ਨਰਿਧਾਰਤ ਨਹੀਂ ਕੀਤੀ ਗਈ ਹੈ। ਅਸੀਂ ਹਾਲ ਹੀ ਵੱਚਿ ਪ੍ਰਕਾਸ਼ਤ ਇਨਵਾਕੋਸਟ ਡੇਟਾਬੇਸ (InvaCost database) ਅਤੇ

પૂરક જાણકારી ਦੇ અપાર ડે, કુલ 2078 વલિંખન લાગત ઐટરીઓ લઈ, 1960 ડે આસટરેલીઆઈ આરથિકતા ઉંડે ધાડવી પૂરજાતીઓ નાલ જુડીઓ ખચરો ડા ધગિલા વસિથારત વસિલેસન પૂરદાન કરદે ગાં. 1960વિઓ ડે લેકે, આસટરેલીઆ ને ધાડવી પૂરજાતીઓ ડે ઘંટે ઘંટ 298.58 US ઘલિંખન ડાલર (2017 મુલ) જાં 389.59 AU ઘલિંખન ડાલર (2017 ઐસઝ ઐકસચેન રેટ) ડા ખરચ કીઝા રૈ જાં નુકસાન ધાઈઆ રૈ. ગાલાંક, ઈર ઈંક ઘંટ ઐંદાજા રૈ કનિજવિં જવિં સકઝી કાનૂન ડે ઘાઅદ અનુમાન ડી ગનિઝી વધડી રૈ, લાગઝાં વૈંચ વાધા રુંદા રૈ. 1970 વિઓ ડે લે કે ગુન ડંક, ઠર ડગલે વૈંચ કુલ ખરચિઓ વૈંચ ઐસઝ 1.8–6.3 ગુના વાધા રેઈઆ રૈ, જે કાં 6.09–57.91 US ઘલિંખન ડાલર પૂરઝાં સાલ (સારે ખરચે જેઝ કે) જાં 225.31 મલિંખન – 6.84 US ઘલિંખન ડાલર પૂરઝાં સાલ (નઠિંખઅઝ, સઠિઠ ઘરુઝ ડરેસેમંદ ખરચે) ડા અનુમાનઝ ખરચા સી. પંદિઓ ડીઓ પૂરજાતીઓ ડે પૈદા રેન વાલિંખન લાગઝાં રાજ વૈંચ સઝ ડે વૈંચ સન (151.68 ઘલિંખન ડાલર), ગાલાંક જિઓઆડર લાગઝાં ઈક પૂરજાતી કરકે નઠી સન। નડીનાં ડી પઢાન કીઝી પૂરજાતીઓ વૈંચ, સઝ ડે મઠગીઓ સન સાલાના રાઈગીગ્રાસ (લેલિંખન રનિંજીઢમ), ધારઘીનીઅમ (ધારઘીનીઅમ ઠસિટેરેફેરસ) અઝે રૈગવૈંટ (સેનેસિંઈ જાકેઘીઆ)। ઘાર સઝ ડે મઠગીઓ સુરેઠીઓ ઘનઠાઈઓ (48.63 ઘલિંખન ડાલર), કીઝે (11.95 ઘલિંખન ડાલર), જુઢિકિટસ (4.10 ઘલિંખન ડાલર) અઝે મેનેકેટસ (1.92 ઘલિંખન ડાલર) સન। ડીન મઠગીઓ પૂરજાતીઓ સન – ઘોલિંખન (ફેલસિ કૈટસ), ખરગોસ (ઈરિકટેલાગસ કનલિલસ) અઝે લાલ આજાઝ કીઝી ઐંગ કીઝીઓ (સેલેનેપસિ ઈનવિકિટા)। ઠરેક રાજ / ખંઝિ વૈંચ પૂરજાતીઓ ડુઆરા વૈંકે ખરચિઓ ડા વૈંચરા સમુઠ સી, ધર પૂરઝી રાજનિઝીક ઈકાઈ વૈંચ જિઓઆડર (3–62%), ઈક ડે ડીન પૂરજાતીઓ લઈ ખરચા કીઝા જાંદા સી। ઠપિરટ કીઝે ખરચિઓ વૈંચ જિઓઆડર (61%) ઘરુઝે વાઝાવરઝ ડે લાગુ રુંદે ઠન અઝે કુલ ડા 73% કેવલ પૂરઘંપન ખરચિઓ ડે મુકાઘલે સંધિ નુકસાન જાં ઘાટે નાલ સઘંપન રૈ, જડકા ઈર ડેવે ઘેજાં ઐકઝિઓ ડી ઊપલઘઝઝા ઠું ડરસાઉડીઓ ઠન। ધાડવી પૂરજાતીઓ ડે વૈંચ રઠે ઠમલિંખન ડે ખરચિઓ ડા ઝાર આસટરેલીઆઈ આરથિકતા ડે જાઠી રઠેગા, ધર ઘરિઝર નવિંસ, મઠિઠારીકરન કીઝે મુલાંકનાં અઝે ઠપિરટ કરન અઝે ઝાલમેલ વાલિંખન ડે ઘલિંખન ડે ઘાઝમ ઠમેઝ) નાલ, ઈરઠનાં વૈંચે કુઝ ખરચિઓ ઠું કાઢી ઠંદ ડંક ઘટાઈઆ જા સકડા રૈ।

### Abstract in Gujarati

#### ઓસ્ટ્રેલિયામાં નોંધાયેલ આફરમક પૂરજાતિઓના આરથિક અર્યનું વગિતવાર મૂલ્યાંકન

ઓસ્ટ્રેલિયાને આફરમક પરપૂરોતીય પૂરજાતિઓના ઇરાદાપૂરક અને આકસમકિ પ્રવેશના લીધે ભારે આરથિક નુકસાન થયું છે. તેમ છતાંય સીધા નુકસાન અને નુકસાન સાથે સંકળાયેલા અર્યની મર્યાદા તેમજ વ્યવસ્થાપન દરમિયાનગીરીઓનો અંદાજ લગાવવો હંમેશા મુશ્કેલ રહ્યો છે. જેનું મુખ્ય કારણ વશિવસનીય અર્ય અંદાજ અને નમૂનાઓની સાપેક્ષતા છે. અમે આ સાથે ઇનવાડીસ્ટ ડાટાબેઝ અને પૂરક માહિતિમાંથી કુલ ૨૦૭૮ નોંધાયેલ ઓસ્ટ્રેલિયાના આધારે ૧૯૬૦ના દાયકાથી ઓસ્ટ્રેલિયાના આફરમક પૂરજાતિઓ સાથે સંકળાયેલા અર્યની ઓસ્ટ્રેલિયાના અર્યતંતર પરની અસરનું પ્રથમ વગિતવાર વશિલેષણ પ્રસ્તુત કરીએ છીએ. ઓસ્ટ્રેલિયાને ૧૯૬૦ના દાયકાથી આફરમક પૂરજાતિઓ પાછળ ઓછામાં ઓછું ૨૯૮.૫૮ અબજ અમેરીકન ડોલર (વર્ષ ૨૦૧૭ની કમિત પ્રમાણે) અથવા ૩૮૮.૫૮ (વર્ષ ૨૦૧૭નો સરેરાશ વનિમિયદર પ્રમાણે) અબજ ઓસ્ટ્રેલિયન ડોલરનો કુલ અર્ય અથવા નુકસાન થયું છે. જોકે, આ એક નીચો અંદાજ છે કારણકે ઘાતાંકના નિયમ પ્રમાણે વધતા અર્યના લીધે અંદાજમાં વધારો થાય છે. વર્ષ ૧૯૭૦થી અત્યાર સુધી પ્રત્યેક દાયકા દીઠ કુલ સરેરાશ અર્યમાં ૧.૮ થી ૬.૩ ગણા વધારાના લીધે વાર્ષિક અંદાજિત અર્યની મર્યાદા ૬૦.૮ થી ૫૭.૯૧ અબજ અમેરીકન ડોલર પ્રતિવર્ષ (તમામ અર્ય સંયુક્ત) અથવા ૨૨.૫૩૧ કરોડ થી ૬.૮૪ અબજ અમેરીકન ડોલર પ્રતિવર્ષ (અવલોકન, માત્ર ખુબ જ વશિવસનીય અર્ય) અંકાઈ છે. વનસ્પતિપૂરજાતિઓથી થયેલ અર્ય સૌથી વધુ હતો (૧૫૧.૬૮ અબજ અમેરીકન ડોલર), જો કે મોટાભાગના અર્ય કોઈ એક પૂરજાતિને આભારી ન હતા. જાણીતી નીદણ પૂરજાતિઓ પૈકી સૌથી અર્યાળ રાજગ્રાસ (લોલીયમ રગિડિમ), પારથેનિયમ (પારથેનિય ડિસ્ટરોફોરસ) અને રાગવોર્ટ (સેનેસિઓ જેકોબીયા) હતા. યાર સૌથી અર્યાળ વર્ગોમાં, સસ્તન પ્રાણીઓ (૪૮.૬૩ અબજ અમેરીકન ડોલર), જંતુઓ/કટિઓ (૧૧.૯૫ અબજ અમેરીકન ડોલર), યુડકિટ્સ (૪.૧૦ અબજ અમેરીકન ડોલર) અને એકદળીય વનસ્પતિ (૧.૯૨ અબજ અમેરીકન ડોલર) હતા. ત્રણ સૌથી અર્યાળ પૂરજાતિઓમાં બધા જ પ્રાણીઓ હતા – બલિડીઓ (ફેલસિ કેટસ), સસલા (ઓરીકટોલાગસ ડ્યુનિક્યુલસ) અને લાલ આયાતી ફાયર કીડીઓ (સોલેનોપસિ ઇનવડિટા) હતા. દરેક રાજ્ય/પ્રદેશોમાં પૂરજાતિદીઠ અર્ય અલગ અલગ હતા. પરંતુ રાજકીય એકમ દીઠ મોટા ભાગનો (૩–૬૨%) ના અર્ય એકથી ત્રણ પૂરજાતિઓમાંથી તારવેલ હતો. મોટાભાગના નોંધાયેલ અર્ય (૬૧%) વવિધિ પૂર્યાવરણ અને કુલ અર્યના ૭૩%, સીધા નુકસાન અને વ્યવસ્થાપન દરમિયાનગીરીઓનો હતો. આ બંને તારણો માહિતીની ઉપલબ્ધતા દર્શાવે છે. આફરમક પૂરજાતિઓના વધતા જતા આફરમણથી ઓસ્ટ્રેલિયન





## Keywords

Ecosystem management expenditure, InvaCost, monetary impacts, non-native species, Oceania, socio-economic damage

## Introduction

Biological invasions continue to erode economies, ecosystems and societies worldwide, with no sign of abatement (Simberloff et al. 2013; Bradshaw et al. 2016; Pyšek et al. 2020). As the rate of introductions of invasive alien species accelerates given an increasingly connected world (Seebens et al. 2017), the extent and magnitude of these impacts will *ipso facto* also increase. While in recent decades, much research has examined the ecological effects of invasive species across habitat types, geographic regions and taxonomic groups (Crystal-Ornelas and Lockwood 2020, and references therein), quantification of the economic impacts has remained diffuse. In particular, a lack of resolute, comprehensive and synthesised economic cost estimates precludes adequate comparisons and compilation at, for example, the national level. Such information can help to assist in setting priorities by policy-makers and organisations for managing invasive species in some of the most impacted countries.

Recently, the InvaCost database was developed to provide the most comprehensive and standardised compilation of invasion costs globally (Diagne et al. 2020b). This advance now addresses the aforementioned limitations by presenting economic costs at a global scale, yet with sufficient resolution to enable assessment in more granular national, taxonomic and socioeconomic contexts. Further, InvaCost allows for assessment of the reliability of cost estimates, as well as for whether costs are predicted to occur or have been empirically observed. While broad-scale perspectives of the economic costs of invasive species are needed because of the transboundary nature of invasions, national or regional assessments are still required in much greater detail (Diagne et al. 2020a).

Australia – the sixth largest country (7,688,287 km<sup>2</sup>) and thirteenth largest economy (2017 gross domestic product = US\$1.23 trillion; worldbank.org) in the world, as well as the only true ‘island’ continent apart from Antarctica – has a long history of deliberate and accidental introductions of invasive species (Hoffmann and Broadhurst 2016). Introductions by humans go back as far as 5,000–10,000 years with the deliberate introduction of the dingo (*Canis dingo*) (Smith et al. 2019) and, today, many different alien species occupy almost every terrestrial, freshwater and marine habitat in the country. Indeed, some of the most infamous international examples of deleterious invasive species are Australian – cane toads (*Rhinella marina*) (Lever 2001), prickly pear cactus (*Opuntia* spp.) (Freeman 1992), swamp buffalo (*Bubalus bubalis*) (Ridpath and Waithman 1988), foxes (*Vulpes vulpes*) (Saunders et al. 2010) and European rabbits (*Oryctolagus cuniculus*) – to name a few. While there have been some successes in suppressing various alien species using biological control and corresponding savings in averted damage, such as the prickly pear cactus (Raghu and Walton 2007) and European rabbits (Cooke et al. 2013), most invasive species represent major ongoing ecological, agricultural and economic problems for the country.

While there have been previous attempts to evaluate the costs of invasive species to the Australian economy, these have either focussed on one or only a few taxa, or have been restricted to particular regions. Only the impacts of invasive plants have been the subject of analyses at the kingdom level (e.g., Sinden et al. 2004). Moreover, most assessments have been reliant on flawed assumptions (Sagoff 2008; Holmes et al. 2009) and extrapolations (Pimentel et al. 2001) or have applied more top-down approaches to estimate costs by sector, rather than to divide the estimates among species, regions, sectors or decades (McLeod 2004; Sinden et al. 2004; Gong et al. 2009; Hoffmann and Broadhurst 2016; Llewellyn et al. 2016).

Here we focus on Australia and its territories to provide the first detailed assessment of the reported economic costs of invasive species since the 1960s, based on records extracted from the recently published InvaCost database (Diagne et al. 2020b), combined with both an independent database of costs restricted to invasive herbivore species (previously unpublished) and recent data describing the costs of invasive plants and other disease-causing agents. Our aims are to (i) assess the reliability (values based on actual measures as opposed to non-sourced estimates) of the Australian cost estimates, as has been done previously for invasive insects (Bradshaw et al. 2016) and invasive species globally (Diagne et al. 2021), (ii) provide a State/Territory summary of those costs, (iii) identify the costliest species nationally and by State/Territory, (iv) investigate the most impacted environments and sectors and (v) estimate robust temporal trends in the economic costs of invasive species over the last five decades.

## Methods

### Data collection

To determine the cost of invasive species to the Australian economy, we used cost data collected in the InvaCost database (Diagne et al. 2020a, b) ( $n = 2,419$  entries) concerning the global costs of invasive species, based on published literature, enabling comprehensive quantification of costs associated with invasive species at various spatio-temporal scales. Of these, 877 (36%) entries pertained to Australia. The data in InvaCost were collected following a series of literature searches using the Web of Science platform ([webofknowledge.com](http://webofknowledge.com)), Google Scholar ([scholar.google.com](http://scholar.google.com)) and the Google search engine ([google.com](http://google.com)) and all the retrieved costs were converted to a common, up-to-date currency (2017 US\$; [data.worldbank.org](http://data.worldbank.org)).

We complemented the InvaCost data in three ways. We first added supplementary cost data from new references containing cost information (~ 2300 entries; <https://doi.org/10.6084/m9.figshare.12928145>). Next, we added data from the “Costs of Invasive Herbivores in Australia” database compiled by Biosecurity South Australia in 2018. The latter is an unpublished database compiled by L.A. to collate peer-reviewed and government documents reporting estimated costs specifically for ‘invasive’ herbivores [this can include native species, which compete with human

interests in some cases – for example, kangaroos (various species, notably *Osphranter* and *Macropus* spp.)). That database also includes pigs (*Sus scrofa*) and birds, even though these species are not all strictly herbivores. Based on the top five commodities in each of the categories of livestock, crops and horticulture as a starting point, the impacts from pest animals on those commodities were compiled for each. Estimates were identified using Google Scholar and Google search engine for peer-reviewed papers, conference papers, surveys and reports (e.g. Australian Bureau of Agricultural and Resource Economics, Invasive Animals Cooperative Research Centre, government and industry reports).

As a last step, we augmented the database with additional, missing cost estimates identified during the review process, as well as additional searching. We included all new costs following the structure, decision points and rules of the original InvaCost data (Diagne et al. 2020b). Many of the additional costs were derived from a single, large report on weeds of cropping systems by Llewellyn et al. (2016). The reporting units used in that report were the Grain Research and Development Corporation agroecological zones and some of these zones crossed state-government boundaries. To assign costs to the State level where an agroecological zone crossed State boundaries, we assumed that costs were evenly distributed across each zone and divided the reported costs proportionally into their respective States. Furthermore, Llewellyn et al. (2016) reported the annual ongoing costs of weed management and these costs were updated by McLeod (2018) for the year 2018 and onwards. To avoid double counting these costs, we extended the Llewellyn et al. (2016) costs up to 2017 and used McLeod (2018) from 2018 onwards. These added costs included new estimates that included the present year (2020). At the time of writing, there were no exchange rates or consumer price index data available from the chosen InvaCost sources. As such, we used an 11-month average (Jan–Nov 2020) exchange rate taken from [rba.gov.au/statistics/historical-data.html](http://rba.gov.au/statistics/historical-data.html). We calculated the relevant consumer price index by taking the 12-month average change to November 2020 reported at [bls.gov](http://bls.gov) and applied it to the 2019 consumer price index reported by the chosen InvaCost data source ([data.worldbank.org](http://data.worldbank.org)).

We reviewed all sources, as well as the references they cited, to identify additional sources. Each entry recorded: (i) species identity ('general' if unspecified); (ii) reported cost (including range if available; no hypothetical costs included); (iii) jurisdiction (including area of coverage if provided); (iv) applicable year(s) (set to year of publication if not provided); (v) implementation (observed or extrapolated); (vi) method (field, desktop, both); (vii) verification (whether approach could be identified/repeated); and (viii) type (control, loss, research, damage, mixed).

After combining the separate databases and standardising/aligning columns, we removed obvious duplicate cost estimates (i.e. same cost figures from (non-)identical sources) following previous protocols (Bradshaw et al. 2016; Diagne et al. 2020b). Following our data processing (see below), we finished with a total of  $n = 2257$  unique entries pertaining to Australia for analysis (database available for download at <https://doi.org/10.5281/zenodo.4455979>).

## Estimating total costs

Deriving the total cumulative costs of the impacts and management of invasive species over time requires considering the temporal period to which a particular cost estimate applies. We calculated the duration of a cost as the number of years between the probable start and end years provided in the full database. When the exact start year was unknown, we conservatively considered the year of publication of a primary data source as either the start year or the end year, to which the duration (if mentioned) in number of years was considered (by adding or subtracting the number of years) to derive either, respectively, the end or the start year (Diagne et al. 2020b). We did not use data describing costs prior to 1960 to avoid inconsistencies in currency conversion. We also removed all costs identified as ‘avoided’ because of a given intervention (i.e. unrealised costs).

To calculate the total cumulative cost, we first recalculated all the annual costs for the defined periods of their occurrence using the `invacost` package in R via the `expandYearlyCosts` function (Leroy et al. 2020) and then summed them to obtain total costs. We also estimated the invasion costs for a series of sub-categories by summing all entries according to six descriptive columns in the database: (1) **method reliability** – the perceived reliability of cost estimates, based on the type of publication and method of estimation (*low* or *high*); following Diagne et al. (2020b), ‘high reliability’ is accorded if either provided by pre-assessed materials (e.g. peer review, official reports) or using a documented, repeatable and/or traceable method when provided in other grey literature; (2) **region** – here, we split costs by major political unit in Australia (States and Territories), as well as costs not associated with any particular unit (i.e. national-scale or multiple states/not stated); (3) **implementation form** – this refers to whether the cost estimate was actually realised in the invaded habitat or merely predicted (*observed* or *potential*); (4) **type of environment**: *aquatic*, *terrestrial* or *mixed* habitats (species that spend part of their life cycle in water); (5) **type of cost** – (i) *damage/loss* (damage or losses incurred by invasion), (ii) *expenditure* (control-related expenditure, such as monitoring, prevention, management or eradication), (iii) *general* costs, including research and administrative costs and (iv) *mixed* types; and (6) **impacted sector** – the activity, societal or market sector that was affected by the cost – these were *agriculture*, *authorities-stakeholders*, *energy*, *environment*, *forestry*, *health*, *public and social welfare*, *protected areas* and *trade*. We modified individual cost entries not allocated to a single sector to *mixed* in the **impacted sector** column. We also provide several taxonomic summaries of the costs to provide the reader with a full appreciation of the relative scale of costs among different contributors. These include by taxonomic Kingdom and taxonomic Class.

## Temporal development of costs

For the temporal estimation of the average annual costs, we used the custom `invacost` package in R (Leroy et al. 2020). This package provides functions for modelling the temporal trend of costs using a selection of both linear and non-linear models to provide a summary and comparison of their respective outputs. Given the evidence that numbers of invasive species show no sign of saturation (Seebens et al. 2017), we

expected their associated costs to be stable or increase. We accounted for the effects of time lags between the occurrence of the costs and their reporting by examining ‘impact year’ relative to ‘publication year’. This is because there were often several years between the occurrence of costs and the time when they were reported in the literature (Diagne et al. 2021). Here, we determined from both the highly reliable, observed costs and all costs combined that the lag quantiles were: 25% = 0 year; 50% = 1 year and 75% = 3 years. We therefore estimated the ‘final’ costs for the year 2017 (i.e. three years prior to 2020) in the trend analysis described below – this ensures that we include only the most complete years in the trend analysis (i.e. years expected to have > 75% of cost data).

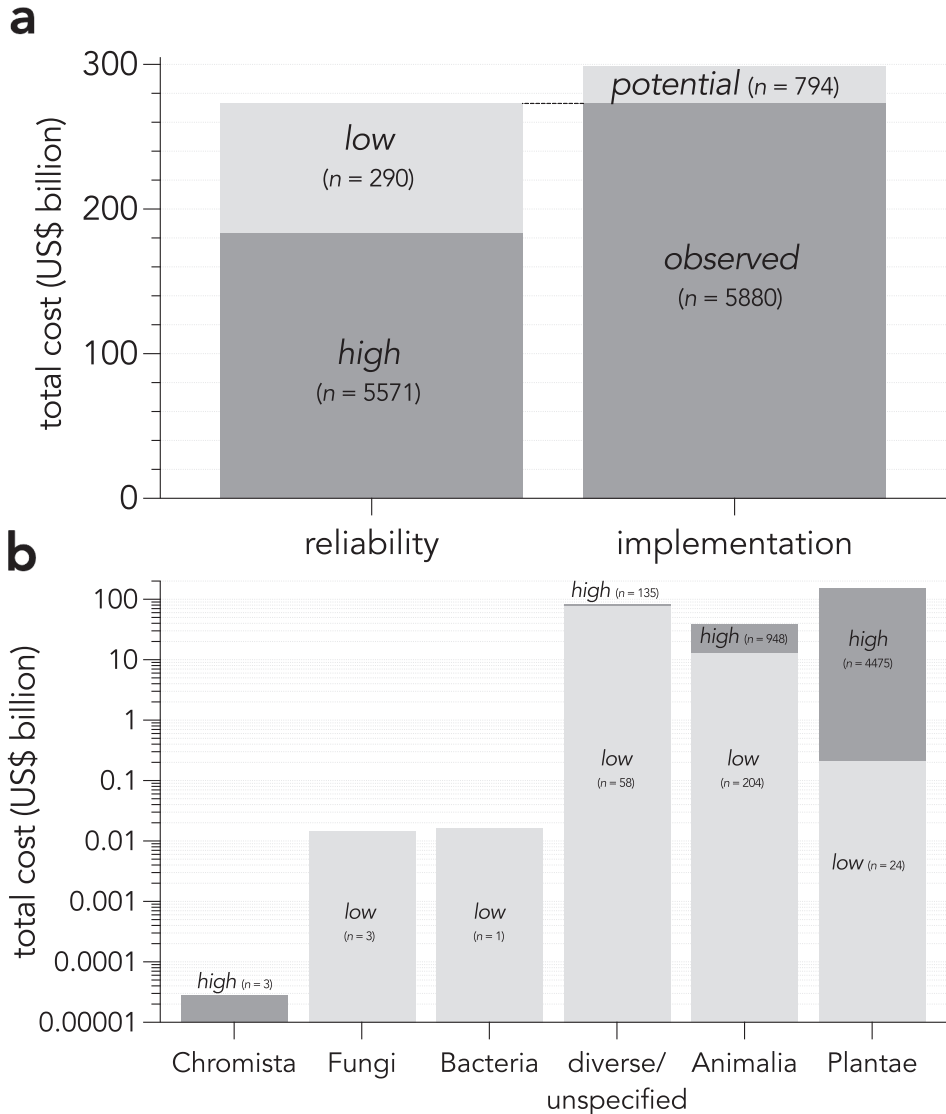
We applied five different models to quantify the temporal dynamics of reported  $\log_{10}$  costs (*costTrendOverTime* function in the *invacost* package; now *modelCosts* in the latest version of R) because we had no *a priori* reason to assume that the trends were monotonic (linear or otherwise). The simplest approach is an ordinary least-squares regression (two variants: linear and quadratic to test for monotonic trends or non-linear behaviour, respectively). Additionally, we applied two variants of a robust regression (linear, quadratic – R package *robustbase*) (Maechler et al. 2020) because the cost data are heteroscedastic (unequal variances) and temporally autocorrelated. We therefore estimated the covariance matrix with heteroscedasticity and autocorrelation-consistent estimators (Andrews 1991) to derive 95% confidence intervals for our models. Robust (MM-type) regression (Yohai et al. 1991; Koller and Stahel 2011) applies iteratively reweighted least-squares to reduce the influence of outliers on parameters estimates. Finally, we applied a generalised additive model (GAM – R package *mgcv*) (Wood et al. 2016). Generalised additive models use smoothing functions to account for heteroscedasticity, based on a Gaussian location-scale model family. A more detailed description of the methods we applied is provided in Diagne et al. (2021).

We applied these five different models to both the entire cost dataset for Australia, as well as the highly reliable, observed costs only, to predict model-averaged ‘final’ (for 2017) (Diagne et al. 2021) estimated costs, based on the temporal trends of the full and subset data. This incorporates both parameter uncertainty estimated in individual models, as well as model uncertainty regarding the true underlying fit. We did this in two ways: (1) we first calculated Akaike’s information criterion weights (Burnham and Anderson 2002) for the three likelihood-based models (ordinary least-squares regressions and generalised additive model) and (2) using the root mean-squared errors as weights to calculate a weighted-mean cost in 2017 (all five models). In addition to the *invacost* package, all R code and the Australia-specific dataset needed to reproduce the analyses can be accessed on Github via <https://doi.org/10.5281/zenodo.4455979>.

## Results

### Total cost

Since 1960, the total estimated cost of invasive species to Australia was US\$298.58 billion (2017 value), based on 2078 unique entries (after removing 179 records pertain-



**Figure 1.** Division of total costs of invasive species in Australia relative to **a** reliability (*high*: dark grey or *low*: light grey) and the form of implementation (i.e. whether the cost estimate was realised [*observed*] or predicted [*potential*]) **b** costs according to major kingdoms. The number of unique database entries (*n*) in each category is indicated in brackets.

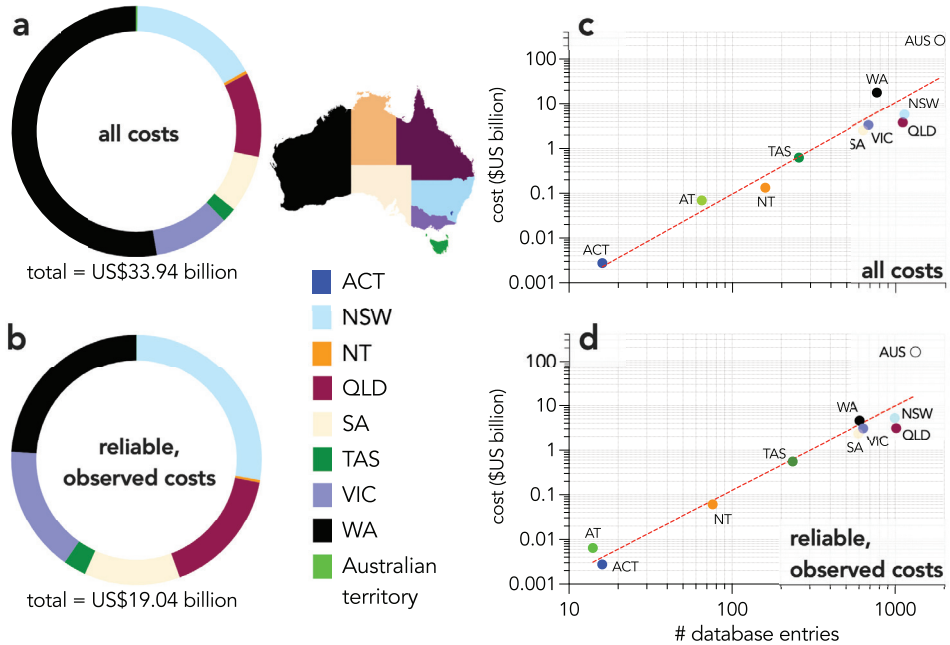
ing to avoided costs) in the combined database (6674 expanded yearly values), which is approximately equivalent to AU\$389.59 billion (2017 average exchange rate). Of the total costs, the majority (91.6%) were observed (US\$273.37 billion) rather than predicted or extrapolated ('potential'; US\$25.21 billion) (Fig. 1a). Of the observed costs, most (61.3%) were considered highly reliable (US\$183.04 billion).

Considering all costs regardless of reliability and implementation type, 27.6% of the total (US\$82.29 billion) was not attributable to a single kingdom or was unspecified (Fig. 1b). This arises mainly from a multi-species assessment of costs of invasive species across all of Australia (Hoffmann and Broadhurst 2016). However, when considering only observed, highly reliable estimates, the costliest kingdom of invasive species was plants (US\$151.68 billion), followed by animals (US\$26.43 billion), with 'diverse/unspecified' making up only 2.7% of these (135 estimates amounting to US\$4.93 billion) (Fig. 1b). There were few entries for Kingdoms Chromista ( $n = 3$ ; US\$27,970), Fungi ( $n = 3$ ; US\$14.69 million; all low reliability; many of the fungal plant pathogens were not specified to Kingdom in the source data and so were designated 'diverse/unspecified') and Bacteria ( $n = 1$ ; US\$16.49 million; low reliability) (Fig. 1b).

There was a large disparity in the proportional attribution of costs by major political unit (States and Territories) whether estimating all costs or focussing on the highly reliable, observed costs only. Aside from the costs not clearly associated with a particular State or Territory (i.e. nation-wide or not specified), Western Australia had the highest total costs (52.7%) when considering all costs (US\$17.88 billion) (Fig. 2a) – 69.3% of this value is attributed to rats *Rattus rattus* (US\$12.39 billion), but > 99% of this estimate is considered to be of low reliability. When considering only the highly reliable, observed costs, New South Wales had the highest costs (US\$5.25 billion), followed by Western Australia (US\$4.58 billion) and Victoria (US\$3.09 billion) (Fig. 2b).

There was an approximate power-law relationship between the number of unique database entries and the total costs per political unit for both all costs combined (Fig. 2c) or highly reliable, observed costs only (Fig. 2d). These relationships indicate that, with an increase of one order of magnitude in the number of estimates, the estimated costs increase on average by 2.0 (all costs) or 1.9 (highly reliable, observed costs) orders of magnitude. These power-law relationships were also evident for the cumulative data over time (Suppl. material 1: Fig. S1). The magnitude-order increase in costs with the number of database entries appears to be driven mainly by the variation in land surface area among political units (Suppl. material 1: Fig. S2); however, there is no relationship between costs and the number of database entries per unit area (Suppl. material 1: Fig. S2e, f), suggesting that the intensity of assessment of costs among political units is not systematically different. The Australia-wide or unspecified (to State/Territory) values probably represent some inevitable overlap with the cumulative estimates from the different regions; however, it is impossible to discern to what extent given unspecified attribution in many national-scale analyses (e.g., Hoffmann and Broadhurst 2016).

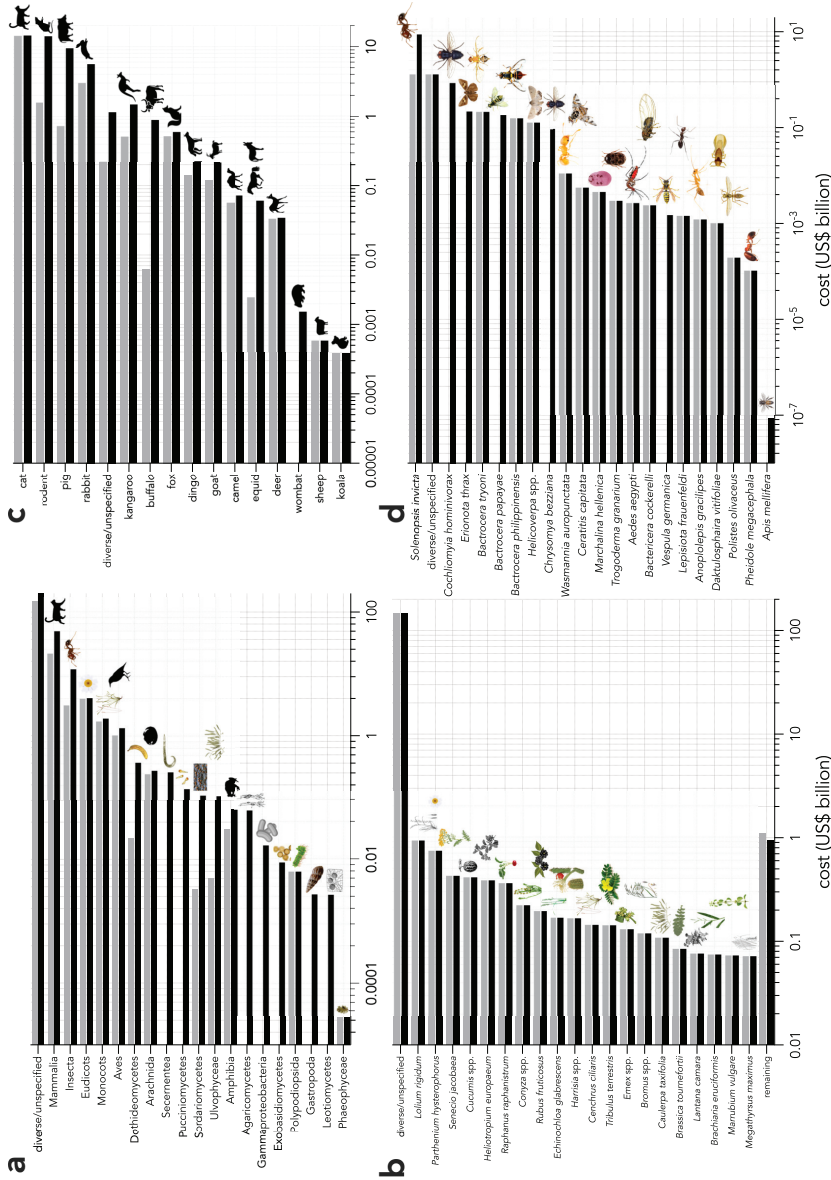
The costliest kingdom (plants) grouped most (96.5%) of its costs into the 'diverse/unspecified' category (Fig. 3b). Of the remaining highly reliable, observed costs identified to species, six species accounted for most (61%) of the remaining costs: annual ryegrass (*Lolium rigidum*), parthenium (*Parthenium hysterophorus*), ragwort (*Senecio jacobaea*), cucumis melons (*Cucumis* spp.), common heliotrope (*Heliotropium europaeum*) and wild radish (*Raphanus raphanistrum*) (Fig. 3b). Other invasive plants have



**Figure 2.** **a** sum of all costs according to attributable major political unit **b** sum of highly reliable costs only by political unit **c** relationship between the number of database entries and all cost estimates by political unit – this also includes the estimate for ‘Australia’ (‘AUS’; not directly attributable to a single State or Territory). The power-law relationship is also shown (evidence ratio = 18013,  $R^2 = 0.90$ ) **d** relationship between number of database entries for highly reliable costs estimates by political unit (evidence ratio = 38550,  $R^2 = 0.91$ ). Abbreviations: ACT = Australian Capital Territory; NSW = New South Wales; NT = Northern Territory; QLD = Queensland; SA = South Australia; TAS = Tasmania; VIC = Victoria; WA = Western Australia; AUS = nation-wide or not specified to which political unit the estimate belongs. ‘Australian territory’ refers to regions outside State/Territory jurisdiction (e.g. Christmas Island, Lord Howe Island).

historically had enormous negative impacts on Australian agriculture, but successful biological control programmes have largely eliminated these costs (e.g. prickly pear cactus and Paterson’s curse *Echium plantagineum*) (Cullen et al. 2012). Some high-cost invasive grasses, such as gamba grass (*Andropogon gayanus*) (Northern Territory Government 2008), were invariably grouped within this ‘diverse/unspecified’ category and so species-specific cost estimates were not available. In Australia, exotic grasses have major environmental (e.g. gamba and buffel *Cenchrus ciliaris* grasses) and agricultural impacts (e.g. *Nassella* tussocks).

The costliest taxonomic classes of invasive species across all of Australia are mammals, insects and eudicots (respectively), although most estimates cannot be attributed to a single class (Fig. 3a). Among the mammals, cats, rodents (mice *Mus musculus* and rats *Rattus* spp.), pigs, rabbits and foxes had the highest costs, accounting for 95% of the total highly reliable, observed costs in this class (US\$20.19 billion; Fig. 3c).

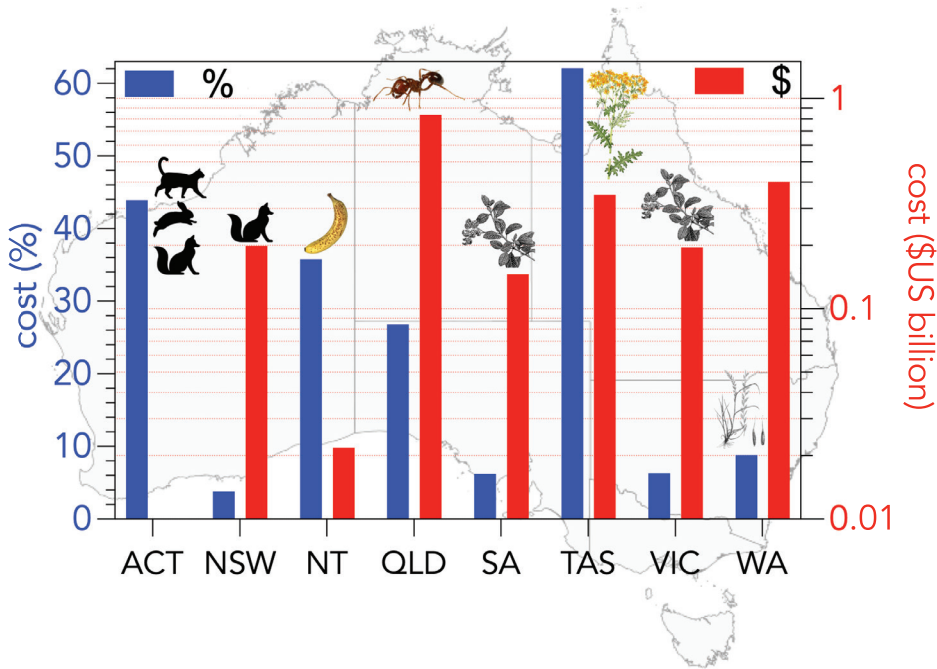


**Figure 3.** Sum of all (black) and highly reliable-only (grey) costs according to **a** taxonomic class **b** by plant species **c** by mammal species and **d** by insect species. We generally ordered these by the highly reliable costs, but, in some cases where there were no highly reliable costs for a particular category, we placed the category in the order suggested by total costs.

In fact, the category of ‘diverse/unspecified’ included these five taxa in many multi-species assessments; so, the costs attributed to these are actually higher. Including low-reliability costs would suggest that rodents – namely, house mice and rats *Rattus* spp. – were the second-costliest mammals, but most (89%) of this total was attributed to the low-reliability category. We also reported cost estimates for five native species groups, including various kangaroo species, koalas (*Phascolarctos cinereus*), common wombats (*Vombatus ursinus*), dingoes (*Canis dingo*) and Queensland fruit flies (*Bactrocera tryoni*) given that they are often considered ‘overabundant’ native ‘pest’ species because they compete for grazing resources (kangaroos), consume trees in *Eucalyptus* spp. plantations (koalas), burrow in paddocks (wombats), kill livestock (dingoes) or damage crops outside their native region (Queensland fruit fly). Kangaroos, koalas and wombats together account for only 3.1% of the total including all costs and 2.4% of the total highly reliable, observed costs (99.9% of which is attributed to kangaroos alone). Dingoes are native to Australia (Smith et al. 2019), but here we included all accounts of ‘wild dogs’, ‘dogs’ and ‘dingoes’ as dingoes – adding dingoes to the native-species groups increases the percentage represented to 3.5% (all) and 3.1% (highly reliable) (although this percentage is slightly higher in reality because dingo-related costs are sometimes combined with other species). Of course, many other native species cause extensive damage to the agricultural industry, such as birds and many insect species, but reliable estimates of the costs associated with most of these species have not been made for Australia.

Within the second-costliest class (insects), most (41.5%) of the highly reliable, observed total is within the ‘diverse/unspecified’ category (Fig. 3d). Of the highly reliable, observed cost estimates attributed to single species, 70.7% of the total is from the red imported fire ant *Solenopsis invicta* (US\$1.29 billion), 11.8% from the (native to tropical Australia, but considered invasive elsewhere) Queensland fruit fly *Bactrocera tryoni* (US\$215.45 million), 8.7% from the Pacific fruit fly *Bactrocera philippinensis* (US\$158.91 million) and 7.1% from the bollworm *Helicovera* spp. (US\$129.2 million) (Fig. 3d).

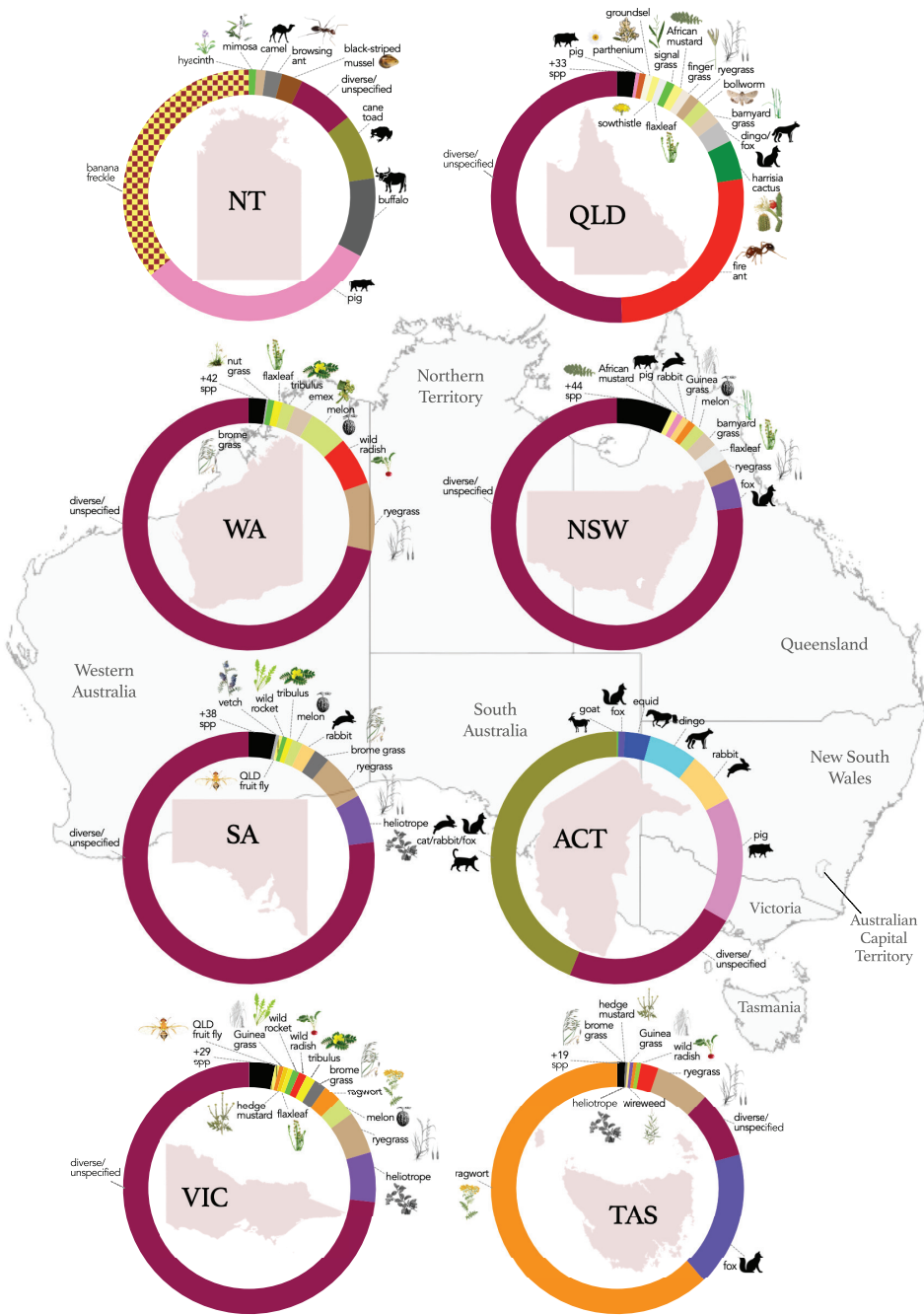
For the third-costliest class, based on all costs combined (Eudicots), five species account for most (56.7%) of all costs attributed to this class: parthenium (18.1%; US\$740.66 million), ragwort (10.4%; US\$425.37 million), cucumis melons (10.1%; US\$412.12 million), common heliotrope (9.4%; US\$384.25 million) and wild radish (8.8%; US\$361.42 million) (Fig. 3b). Many of the other classes are dominated by one or a few species (Suppl. material 1: Table S1); for example, bird costs are either unspecified or from a single species: the common starling (*Sturnus vulgaris*); the Arachnids include only two mites: the red-legged earth mite *Halotydeus destructor* and varroa mite *Varroa destructor*; the Ulvophytes are represented solely by *Caulerpa taxifolia*; the Secernentids include only two nematode species (*Heterodera avenae* and *Pratylenchus* spp.); the Amphibia include only the cane toad *Rhinella marina*; the Polypodiopsids are represented only by *Salvinia molesta*; and the Phaeophyceae (brown algae) include only one species, wakame *Undaria pinnatifida* (see full species list in Suppl. material 1: Table S1).



**Figure 4.** The costliest species (or group of species) per State/Territory. The left axis shows the percentage of the State's/Territory's total highly reliable, observed costs attributable to the species indicated and the right axis shows the value of these species in \$US billion (2017 value). For all States/Territories, except Australian Capital Territory (ACT), Northern Territory (NT) and Tasmania, the costliest category is in fact diverse/unspecified. State/Territory abbreviations and species icons refer to: ACT = Australian Capital Territory (cats, foxes, rabbits); NSW = New South Wales (foxes); NT = Northern Territory (banana freckle disease *Phyllosticta cavendishii*), QLD = Queensland (red imported fire ants); SA = South Australia (common heliotrope *Heliotropium europaeum*); TAS = Tasmania (ragwort *Senecio jacobaea*); VIC = Victoria (common heliotrope); WA = Western Australia (annual ryegrass *Lolium rigidum*).

Various fungal rusts, smuts, rots, mildews and other plant pathogens were also featured in the database, accounting for > \$697 million of the total reported costs (but only \$25.1 million of the highly reliable, observed costs) (Fig. 3a). These included the Dothideomycetes (e.g. banana freckle disease *Phyllosticta cavendishii*), Sordariomycetes (e.g. wheat crown rot *Fusarium pseudograminearum*), Pucciniomycetes (e.g. wheat stripe rust *Puccinia striiformis*), Agaricomycetes (e.g. rhizoctonia disease *Rhizoctonia* spp.), Exobasidiomycetes (e.g. grass smut *Tilletia* spp.) and Leotiomycetes (powdery mildew *Blumeria graminis*).

The costliest species also vary among States/Territories (Fig. 4; also see Fig. 5). Mammals (cats *Felis catus*, red foxes, rabbits) are the costliest species only for Australian Capital Territory and New South Wales (Fig. 4). The Northern Territory's costliest species (36% of its costs) is the fungus *Phyllosticta cavendishii* that causes banana freckle disease. Queensland's costliest species is the red imported fire ant, representing 27% of the total



**Figure 5.** Proportional attribution of costs by species per State and Territory (highly reliable, observed costs only; refer also to Fig. 4). State/Territory abbreviations: ACT = Australian Capital Territory; NSW = New South Wales; NT = Northern Territory, QLD = Queensland; SA = South Australia; TAS = Tasmania; VIC = Victoria; WA = Western Australia. The full list of species (common and scientific names) is provided in Suppl. material 1: Table S1.

highly reliable, observed cost for that State (Fig. 4), whereas the common heliotrope is the costliest species for both South Australia and Victoria (6% of the total highly reliable, observed costs for those States). Tasmania's costliest species (62% of all costs) is the ragwort and Western Australia's is annual ryegrass (9% of total costs) (Fig. 4).

The proportional attribution of the highly reliable, observed costs by species per State/Territory is presented in Fig. 5.

The most impacted habitat is the terrestrial environment (39%), although most (60%) of the total highly reliable, observed costs could not be attributed to a single habitat type (Fig. 6a). Damage by or loss of economic opportunity (cf. management) from invasive species has the highest value (US\$133.35 billion) among cost types (Fig. 6b), representing 72.9% of the total highly reliable, observed costs. The most-affected sectors are the agriculture (24.1%; US\$44.03 billion), health (4.6%; US\$8.37 billion) and environment (4.1%; US\$7.58 billion) sectors, although most (65.8% of the total highly reliable, observed costs) affected multiple sectors (*mixed*; Fig. 6c).

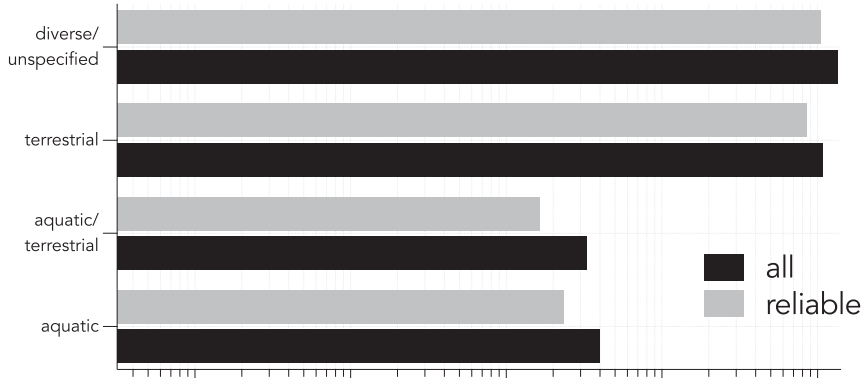
Tracking temporal trends (Diagne et al. 2021), the costs attributed to invasive species in Australia increased from the 1970s to the present. Using all costs irrespective of reliability, the average annual cost increased from US\$57.65 million in the 1970s to \$20.19 billion during the last decade (Fig. 7a). Although highly variable from decade to decade, this equates to an average decadal increase of ~ 6.3-fold (or 3.2-fold, based on the slope coefficient for the linear robust regression only to compare directly to the 3-fold increase estimated from the global dataset) (Diagne et al. 2021). Taking only the reliable, observed costs, the average annual cost increased from over US\$52.35 million in the 1970s to US\$15.12 billion during the last decade (Fig. 7a) or an average 6.0-fold increase per decade (or 1.8-fold, based on the slope coefficient for the linear robust regression). This translates into a mean annual cost of US\$5.85 billion (all costs) or US\$3.58 billion (reliable, observed only) over the study interval (Fig. 7a). Examining the temporal trends in the observed, reliable costs only for three of the main taxonomic groups (plants, mammals, insects) shows the general increasing trend, although the most recent decade's increase is driven primarily by costs attributed to plants (Suppl. material 1: Fig. S3).

For both all-costs and observed, reliable datasets, the general additive model had the best fit assessed using the highest Akaike's information criterion weights ( $wAIC$ ). However, the quadratic ordinary least-squares model had the best fit for the highly reliable, observed costs, based on the lowest root mean-squared error (RMSE; Table 1).

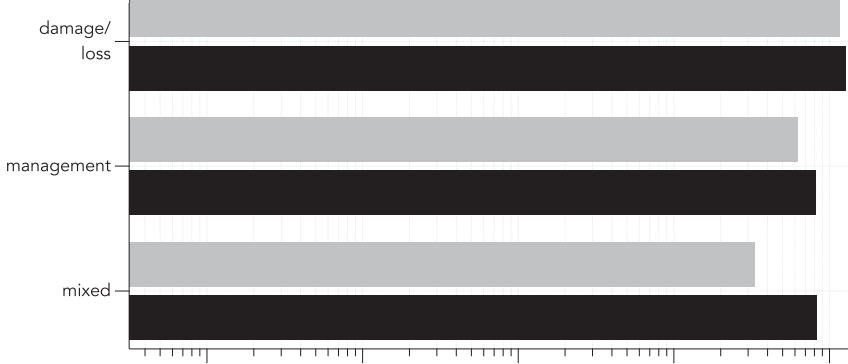
Using these weights to predict the annual costs in 2017 for both datasets, those based on  $wAIC$  are dominated by the GAM prediction, whereas those based on RMSE weights accord relatively more importance to the quadratic models (Fig. 7b, c).

For the all-costs dataset, the estimated annual costs in 2017 are US\$18.77 billion (US\$6.09 billion–US\$57.91 billion) according to  $wAIC$  or US\$17.88 billion (US\$7.56 billion–US\$45.44 billion) according to RMSE (Fig. 7b). For the highly reliable, observed data only, the predictions for 2017 are US\$731.48 million (US\$225.31 million–US\$2.38 billion) according to  $wAIC$  or US\$1.85 billion (US\$484.85 million–US\$6.84 billion) according to RMSE (Fig. 7c).

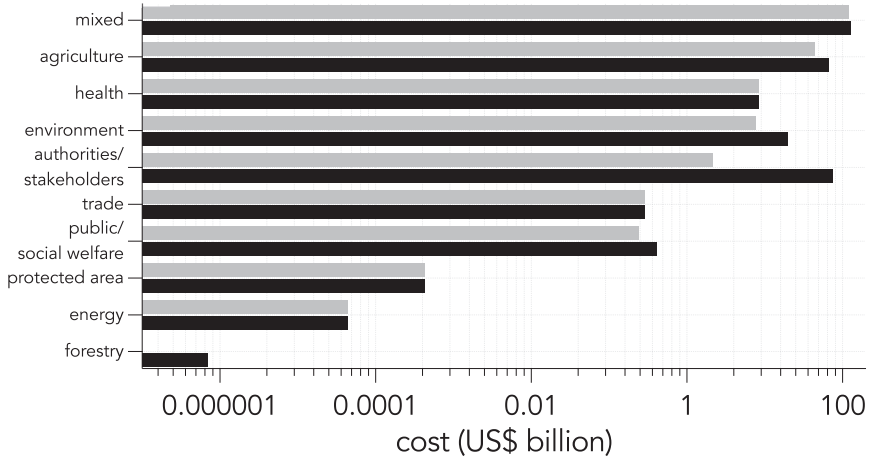
**a: environment**



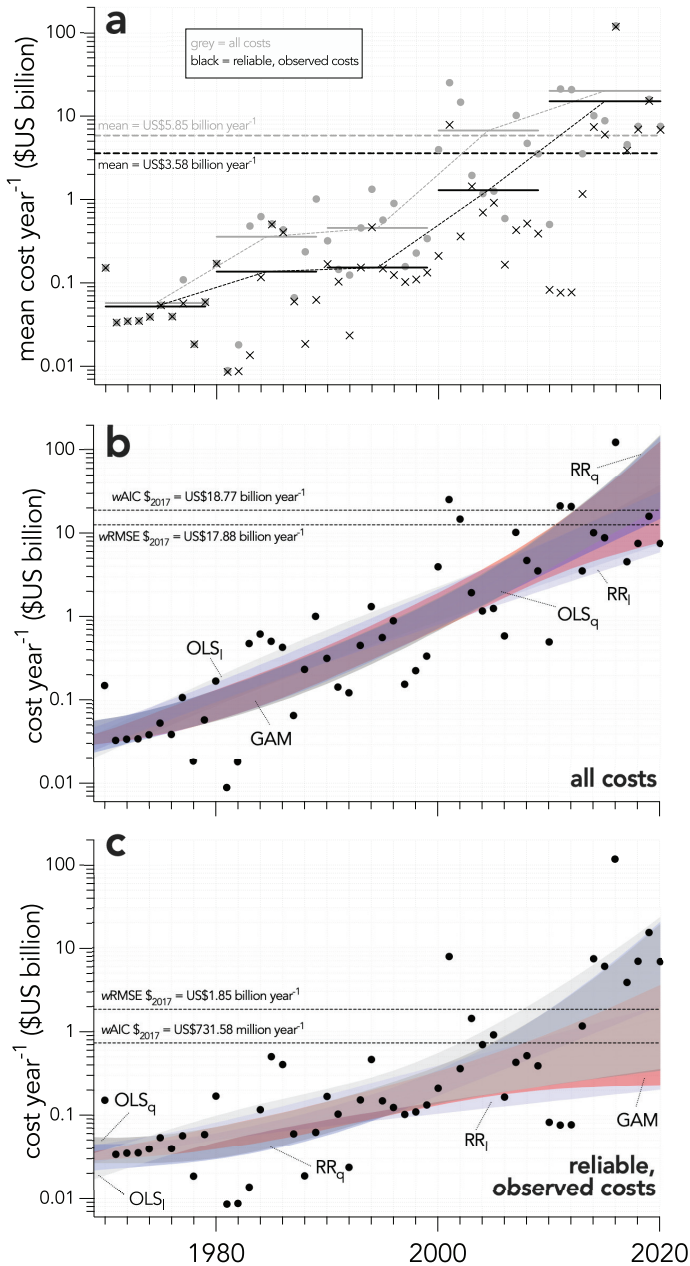
**b: type**



**c: sector**



**Figure 6.** a sum of all (black) and reliable-only (grey) costs ( $\log_{10}$  scale) according the impacted environment **b** cost type and (c) the major impacted sector.



**Figure 7.** **a** raw annual costs for all costs (black) and reliable, observed costs (grey). Also shown are the decadal and overall means **b** predicted annual costs across Australia from 1970 to 2020 for all costs and **c** reliable, observed costs only. Fitted models include OLS<sub>l</sub> = linear ordinary least-squares, OLS<sub>q</sub> = quadratic ordinary least-squares, RR<sub>l</sub> = linear robust regression, RR<sub>q</sub> = quadratic robust regression, GAM = general additive model. Also shown in each panel are  $wAIC_{2017}$  = Akaike’s information criterion-weighted ( $wAIC$ )-average of the predicted annual cost in 2017 (all costs; OLS<sub>l</sub>, OLS<sub>q</sub>, GAM only),  $wRMSE_{2017}$  = root mean-squared error-weighted average of the predicted annual cost in 2017 (all costs; all models),  $wAIC_{2017}$ , and  $wRMSE_{2017}$  (reliable, observed costs only).

**Table 1.** Model fits to the temporal trend of annual costs from 1970 to 2020 for all data combined and for reliable, observed data only. Fitted models include OLS<sub>l</sub> = linear ordinary least-squares, OLS<sub>q</sub> = quadratic ordinary least-squares, RR<sub>l</sub> = linear robust regression, RR<sub>q</sub> = quadratic robust regression, GAM = general additive model. Also shown are Akaike's information criterion weights ( $w_{AIC}$ ) for the three likelihood-based models (OLS<sub>l</sub>, OLS<sub>q</sub>, GAM), the root mean-squared error (RMSE) for all models, the  $R^2$  for each model (% deviance explained in the case of GAM) and the estimates of the relevant model coefficients ( $\beta_{year}$  and  $\beta_{year^2}$ ) and their standard errors ( $\pm$  SE). See also Fig. 7.

model	$w_{AIC}$	RMSE	$R^2$	$\beta_{year} \pm SE$	$\beta_{year^2} \pm SE$
<b>all data</b>					
OLS <sub>l</sub>	< 0.0001	0.4791	0.76	0.0528 $\pm$ 0.0041	–
OLS <sub>q</sub>	< 0.0001	0.4798	0.78	-2.5449 $\pm$ 0.8721	0.0007 $\pm$ 0.0002
RR <sub>l</sub>	–	0.4786	0.76	0.0509 $\pm$ 0.0041	–
RR <sub>q</sub>	–	0.4779	0.79	-2.5807 $\pm$ 1.0377	0.0007 $\pm$ 0.0003
GAM	> 0.9999	0.4676	0.99	–	–
<b>reliable, observed</b>					
OLS <sub>l</sub>	< 0.0001	0.5585	0.50	0.0337 $\pm$ 0.0074	–
OLS <sub>q</sub>	< 0.0001	0.5271	0.55	-2.9986 $\pm$ 1.7180	0.0008 $\pm$ 0.0004
RR <sub>l</sub>	–	0.5816	0.51	0.0251 $\pm$ 0.0055	–
RR <sub>q</sub>	–	0.5277	0.71	-3.2653 $\pm$ 0.9690	0.0008 $\pm$ 0.0002
GAM	> 0.9999	0.5622	0.99	–	–

## Discussion

Aggregated economic costs of the impacts and management of invasive species in Australia have amounted to at least US\$298.58 billion (~ AU\$389.59 billion) since the 1960s and US\$183.04 billion (~ AU\$238.83 billion) when conservatively considering highly reliable, observed costs only. Sampling biases notwithstanding (see below), the greatest economic burden to Australia imposed by invasive species originates from weedy plants, although most of these costs are shared across a wide range of species. This arises because of the ‘top-down’ approaches employed by others previously to estimate costs associated with losses and control specific to particular industries, rather than individual species (e.g., McLeod 2004; Sinden et al. 2004; Gong et al. 2009; Llewellyn et al. 2016). In many circumstances, this approach is more tractable and efficient for estimating total costs to particular sectors.

There are an estimated 2700 exotic plant species established in Australia, of which > 400 are declared weedy or noxious (Hoffmann and Broadhurst 2016). Our database contained highly reliable cost estimates for only ~ 100 species of declared weeds and many weeds did not have species-specific costs as described above. The cost of controlling and the damage done by weeds to the Australian agriculture sector alone are estimated at ~ AU\$4 billion year<sup>-1</sup> (Sinden et al. 2004; Hoffmann and Broadhurst 2016). However, from the perspective of single species, exotic mammals dominate the costs, with cats and rabbits, in particular, showing some of the highest estimates across the entire sample across Australia. For rabbits, it has been estimated that, without the highly successful biological control programme started in the 1950s, the impacts of rabbits in Australia would have been at least US\$53.5 billion (~ AU\$70 billion) higher over the last 50 years (Cooke

et al. 2013). However, the impacts of invasive mammals vary markedly by region, with the tropical regions suffering more from invasive fungi (i.e. banana freckle disease in the Northern Territory) and insects (i.e. red imported fire ant in Queensland) instead.

Hoffmann and Broadhurst (2016) estimated annual costs of invasive species in Australia (loss and management) in 2001–2002 at AU\$12.9 billion and in 2011–2012 at AU\$13.6 billion (2012 values), equivalent to approximately US\$14.26 billion and US\$15.03 billion (2017 value) for direct comparison to our estimates. The estimates of Hoffmann and Broadhurst (2016) hail from five different sources (Canyon et al. 2002; McLeod 2004; Sinden et al. 2004; Gong et al. 2009; de Hayr 2013) of unknown reliability and/or derived from stakeholder surveys. The management ('national') expenditure component of these were AU\$3.0 billion and AU\$3.8 billion for 2001–2002 and 2011–2012, respectively (or US\$3.93 billion and US\$4.20 billion, respectively; 2017 value). In contrast, our study incorporated appraisals of method reliability and implementation type when considering economic costs, presenting both 'total' and more conservative figures. Considering only those more conservative numbers, we found that damage and resource losses attributable to invasive species outweigh (73% of that total) management expenditure, but to a greater extent than indicated in those previous studies. This likely mirrors the relatively small investment of government funding for the management of most invasive species (Hoffmann and Broadhurst 2016) compared to the actual economic damages they incur. However, we acknowledge that our broad categorisations of cost type and implementation likely obscure subtleties associated with production losses, control costs and environmental impacts on a case-by-case basis. Reporting cost categories at finer resolution would likely invoke unacceptable subjectivity in reporting given the diversity of species, approaches, sectors, cost types, analyses and assumptions made in individual reports. We acknowledge, however, that the environmental and social costs recorded in InvaCost should be considered with some caution regarding their interpretation, because they are not strictly similar to market costs recorded in economic sectors (Diagne et al. 2020b). Further, cost categorisations for particular species likely shift in terms of emphasis during the course of invasions, meaning that management investment for many species begins with eradication costs and ultimately changes to suppression via control management as the species becomes established. Indeed, government investments typically target new incursions first, meaning that many of these are unlikely to be captured in the relevant literature.

As most cost estimates are damage arising from invasive plants (weeds), it is understandable why management-related costs represent such a small proportion of the total. However, one invasive mammal species is problematic in this regard – cats. According to the definition of 'reliable' provided for the overall InvaCost database – "Peer-reviewed articles and official documents (e.g. institutional or governmental reports) are likely validated by experts before publication. We assumed, therefore, that all cost estimates collected from these materials may likely be of high reliability" (Diagne et al. 2020b) – we were objectively obliged to include the damage estimate of US\$5.95 billion for this species from Pimentel et al. (2001). However, that particular estimate was based on an unverified national population of 18 million feral cats and a subjective value of a bird

eaten of US\$30 (amount to US\$540 million year<sup>-1</sup>) (Gregory et al. 2014). The subjective extrapolation of the costs of cats was also noted for the USA (Fantle-Lepczyk et al. 2021).

Compared to the global estimates (Diagne et al. 2021), the relatively well-sampled region of Oceania represents ~ 8% (range: 3–22%) of the total average annual costs globally in 2017 according to our database. Further, we found that Australia's rate of cost increase was up to ~ 2 times the rate of cost increase estimated from the global dataset (Diagne et al. 2021), although this observation might be explained in part by a lack of data in other regions compared to relatively well-studied Australia. However, Australia is still likely to be recording only a portion of the total costs of invasive species in the region. Although InvaCost, in general, as well as our enhanced sample from Australia more specifically, represent the most comprehensive and resolute assessments of the costs of invasive species yet available, there are several lines of evidence to suggest that the totals we report here still represent a vast underestimate of the real costs.

The first line of evidence is that the estimated total costs increased by approximately two orders of magnitude with every order-of-magnitude increase in the number of entries. This accords well with other assessments revealing that, as the number of estimates increases, so too do the total costs (Bradshaw et al. 2016; Cuthbert et al. 2021a; Diagne et al. 2021) – in other words, the more economic assessments are done, the more costs are discovered. While this could arise in part from the increasing rate of scientific and related publishing over the last 50 years (Richardson and Pyšek 2008), under-sampled or under-assessed species and regions will necessarily underestimate total costs. This particularly holds true to aquatic and semi-aquatic alien taxa in Australia, with the majority (99.9%) of costs attributed to a particular habitat (i.e. excluding mixed-habitat costs) being terrestrial (observed, highly reliable costs) and terrestrial taxa dominating in most regions. On the global scale, this aligns with the under-representation of aquatic invaders relative to terrestrial ones (Cuthbert et al. 2021b).

The second line of evidence is that many well-known invasive species established in Australia have no associated cost estimates in the database. For example, there was not a single estimate from the Reptilia in the database, yet species like red-eared sliders (*Trachemys scripta elegans*) and corn snakes (*Pantherophis guttatus*) are potentially costly species in some States of Australia (García-Díaz et al. 2017; Toomes et al. 2020). Neither were pet trade-sourced bird species like rose-ringed parakeets (*Psittacula krameri*) (Vall-llosera et al. 2017; Toomes et al. 2020) or fish pests, such as European carp (*Cyprinus carpio*) (Koehn 2004), identified in our cost database. Neither have native birds (Bomford and Sinclair 2002) or insects (Gu et al. 2007) that can heavily damage various crops been adequately assessed for costs (apart from the Queensland fruit fly). Indeed, Gong et al. (2009) reported that birds were the costliest vertebrate group to Australian agriculture. Despite reporting the costs for several fungal plant pathogens, there were notable absences; for example, we could not identify any reasonable costs estimates for *Phytophthora cinnamomi*, despite its being a major cause of crop losses and damage to biodiversity in Australia (Cahill et al. 2008; Hee et al. 2013).

The third line of evidence is that the InvaCost approach mandates avoiding the extrapolation of on-going costs beyond the time period specified by a particular source (Diagne et al. 2020b). We therefore included costs without a specified time window as

single-year costs, meaning that the resultant annualised costs represent a lower boundary of the true costs. While this avoids propagating positive errors through time, it downwards biases the true mean costs. The fourth line of evidence is that the number of invasions in Australia has been increasing linearly for some time (CSIRO 2020), which is a notable improvement from the current exponential trend seen globally (Seebens et al. 2017); this accords well with our temporal analysis indicating an ongoing increase in recorded costs over last few decades (Fig. 7b, c). More broadly, lags in invader impacts considering their year of introduction (Rouget et al. 2016) could mean that it takes decades for economic costs to be realised and reported, just as it takes decades of introductions to become invasions (Essl et al. 2011). Accordingly, future economic impacts will likely result from a different suite of invasive species for which the effects have not yet been fully realised.

## Conclusions

While the major costs of loss and damage arising from invasive species, where tangible, are probably captured reasonably well by our database (the under-sampling bias notwithstanding), management-expenditure estimates are perhaps less reliable. The component of the total costs of invasive species attributed to management expenditure is particularly problematic for several reasons. Indeed, there is no standard procedure for reporting expenditure or costs at any level of government or for private organisations, nor is there a national database of expenditure available (Hoffmann and Broadhurst 2016). A similar argument could also be mounted for damage and loss assessments regarding a lack of a standardised reporting protocol.

As our assessment highlights, the large and growing costs of invasive species to the Australian economy are substantial, but under-estimated because of insufficient coverage and a lack of standardised reporting by management authorities and other agencies. As invasive species continue to increase their ranges and associated impacts across the planet (Bellard et al. 2013, 2016; Seebens et al. 2017; Seebens et al. 2021), we can reasonably surmise that Australia will also suffer many additional, negative economic repercussions from invasive species over the coming decades. Developing better methods of estimating environmental impacts of invasive alien species will also contribute to this. We recognise that such types of economically intangible costs arising from invasive species (Bradshaw et al. 2016) are not captured by the database – for example, ecological damage, erosion of ecosystem services and loss of cultural values are inherently challenging to measure in this regard.

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## Supplementary material I

### Figures S1–S3 and Table S1

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Data type: Additional data and analyses

Explanation note: **Figure S1.** Cumulative costs across Australia expressed relative to the cumulative number of estimates, with an approximate power-law model fit to (a) all costs and (b) highly reliable, observed costs only (also see Fig. 2). **Figure S2.** Power-law relationships between (a, b) total costs and land-surface area of different States/Territories, (c, d) database entries and total land-surface area and (e, f) total costs and database entries per unit area for all costs (top row) and highly reliable, observed costs only (bottom row). **Figure S3.** (a) Raw annual (observed, highly reliable) costs for plants, mammals and insects. Also shown are the overall annual means for each taxonomic group. **Table S1.** List of common and scientific names of species to which costs have been attributed in the Australian database.

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