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The economic costs of biological invasions in Africa: a growing but neglected threat?

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Abstract

Biological invasions can dramatically impact natural ecosystems and human societies. However, although knowledge of the economic impacts of biological invasions provides crucial insights for efficient management and policy, reliable syntheses are still lacking. This is particularly true for low income countries where economic resources are insufficient to control the effects of invasions. In this study, we relied on the recently developed "InvaCost" database – the most comprehensive repository on the monetised impacts of invasive alien species worldwide – to produce the first synthesis of economic costs of biological invasions on the African continent. We found that the reported costs of invasions ranged between US$ 18.2 billion and US$ 78.9 billion between 1970 and 2020. This represents a massive, yet highly underes-

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timated economic burden for African countries. More alarmingly, these costs are exponentially increasing over time, without any signs of abatement in the near future. The reported costs were mostly driven by damage caused by invaders rather than expenses incurred for management. This trend was highly skewed towards a few regions (i.e. Southern and Eastern Africa) and activity sectors (i.e. agriculture) and incurred by a small number of invasive taxa (i.e. mainly three insect pests: *Chilo partellus*, *Tuta absoluta*, *Spodoptera frugiperda*). We also highlight crucial, large gaps in current knowledge on the economic costs of invasions that still need to be bridged with more widespread research effort and management actions across the continent. Finally, our study provides support for developing and implementing preventive measures as well as integrated post-invasion management actions at both national and regional levels. Considering the complex societal and economic realities in African countries, the currently neglected problem of biological invasions should become a priority for sustainable development.

Abstract in Afrikaans

Die ekonomiese koste van uitheemse biologiese indringer spesies in Afrika: ‘n groeiende, maar verwaarloosde bedreiging? Kort titel: Verwaarloosde maar groeiende koste van indringer spesies in Afrika. Uitheemse indringer spesies kan natuurlike ekosisteme en menslike samelewings dramaties beïnvloed. Alhoewel kennis oor die ekonomiese gevolge van indringer spesies belangrike insigte bied vir doeltreffende bestuur en beleid, ontbreek betroubare sintese steeds. Dit geld veral in lande met lae inkomste waar ekonomiese hulpbronne onvoldoende is om die gevolge van indringer spesies te beheer. In hierdie studie het ons vertrou op die onlangs ontwikkelde InvaCost-databasis - die mees omvattende opslagplek vir die monetêre impak van indringer uitheemse spesies wêreldwyd - om die eerste sintese van ekonomiese koste van indringer spesies op die vasteland van Afrika te lewer. Ons het gevind dat die gerapporteerde koste van indringer spesies wissel tussen US $ 18,2 miljard en US $ 78,9 miljard gedurende 1970 tot 2020. Dit verteenwoordig ‘n massiewe, maar tog hoogs onderskatte, ekonomiese las vir Afrikalande. Meer kommerwekkend is dat hierdie koste mettertyd eksponensieel styg, sonder enige tekens van vermindering in die nabye toekoms. Die gerapporteerde koste is meestal weens skade van die indringer spesies eerder as uitgawes wat vir die bestuur daarva aangegaan is. Hierdie neiging was sterk skeefgetrek deur enkele streke (Suider- en Oos-Afrika) en aktiwiteitsektore (veral landbou) en is veroorsaak deur ‘n klein aantal indringer taksa (hoofsaaklik drie insekplae: *Chilo partellus*, *Tuta absoluta*, *Spodoptera frugiperda*). Ons beklemtoon ook belangrike groot leemtes in die huidige kennis oor die ekonomiese koste van indringer spesies wat nog oorbrug moet word met behulp van wyer navorsings en bestuursaksies op die vasteland. Ten slotte bied ons studie ondersteuning vir die ontwikkeling en implementering van voorkomende maatreëls, sowel as geïntegreerde bestuursaksies op beide nasionale en streeksvlak. Met inagneming van die komplekse samelewings- en ekonomiese realiteit in Afrikalande, moet die tans verwaarloosde probleem van indringer spesies ‘n prioriteit word vir volhoubare ontwikkeling.

Abstract in Amharic

የሥነ-ሕይወታዊ ወረራዎች ኢኮኖሚያዊ ወጪዎች - እየጨመረ የመጣ ግን ችላ የተባለ ስጋት?
አጭር ርዕስ፡ ችል የተባለ ግን እየጨመረ የመጣ የሥነ-ሕይወታዊያን ወረራ በአፍሪካ ረቂቅ
ሥነ-ሕይወታዊ ወረራዎች በተፈጥሯዊ ሥነ-ምህዳር እና በሰው ማኅበረሰብ ላይ ከፍተኛ ተጽዕኖ ያሳድራሉ። ሆኖም ምንም እንኳን ስለ ሥነ-ሕይወታዊ ወረራዎች ኢኮኖሚያዊ ተጽዕኖ ያለው እውቀት ቀልጣፋ ቁጥጥርን እና ፖሊሲን በተመለከተ ወሳኝ ግንዛቤዎችን የሚሰጥ ቢሆንም፣ አስተማማኝ ውህደት (ቅንጅት) ግን አሁንም ይጎለዋል። ይህ ሁኔታ በተለይ የሥነ-ሕይወታዊ ወረራዎችን ተፅእኖ ለመቆጣጠር በቂ ኢኮኖሚያዊ ሀብት በሌላቸው አገሮች የሚታይ ሀቅ ነው። በዚህ ጥናት፣ እኛ በቅርቡ ኢንቫኮስት የተባለ የመረጃ ቋት (በዓለም ዙሪያ

በወራሪ የውጭ ዝርያዎች የገንዘብ ተጽዕኖዎች ላይ እጅግ የተሟላ መረጃ ያለው የመረጃ ቋት) ባጠናቀረው መረጃ ላይ ተመርኩዘን የመጀመሪያዉን በአፍሪካ ውስጥ ሥነ-ሕይወታዊ ወረራዎች የሚያደርሱትን ኢኮኖሚያዊ ወጪዎች ማጠናቀር ችለናል። በዚህ መሰረት እ.ኤ.አ. ከ 1970 እስከ 2020 ባሉት ዓመታት የተዘገቡ የሥነ-ሕይወታዊ ወረራዎች ወጪዎች ድምር በ 18.2 ቢሊዮን እና 78.9 ቢሊዮን የአሜሪካ ዶላር መካከል መሆኑን ደርሰንበታል። ይህ አሃዝ በጣም ተቃሎ (ዝቅ ተደርጎ) የተገመተ ወጪ ቢሆንም ለአፍሪካ አገራት እጅግ ከፍተኛ ኢኮኖሚያዊ ሸክምን ይወክላሉ። በጣም በሚያስደነግጥ ሁኔታ እነዚህ ወጪዎች በቅርቡ ምንም የመቀነስ ምልክቶች ሳያሳዩ ከጊዜ ወደ ጊዜ በከፍተኛ ሁኔታ እየጨመሩ ይገኛሉ። ሪፖርት የተደረጉት ወጪዎችም ቢሆኑ በአብዛኛው ወራሪዎቹን ለመቆጣጠር ከሚወጡ ወጪዎች ይልቅ በወራሪዎቹ የሚደርሱ ጉዳቶች ላይ ያተኮሩ ናቸው። ይህም ሂደት ወደ ተወሰኑ የክፍለ አህጉሩ አከባቢዎች (ማለትም ወደ ደቡብ እና ምስራቅ አፍሪካ) እና የስራ ዘርፎች (ማለትም ግብርና) በጣም ያዘነበለ ሆኖ በጥቂት ወራሪ ዝርያዎች (ማለትም በዋናነት በሶስት ተባይ ነፍሳቶት፣ በሳይንስ ስማቸው ቺሎ ፓርቴሉስ፣ ቱታ አብሶሉታ እና ስፖዶፕቴራ ፍሩጂፔርዳ) የደረሰ ጥቃት ላይ ያተኮረ ነው። በተጨማሪም በዚህ ጥናት በአህጉር ደረጃ በተስፋፉ ጥናትና ምርምር ጥረቶች እና መቆጣጠሪያ እርምጃዎች ሊሞሉ የሚገቡ ወሳኝና ትላለቅ የሥነ-ሕይወታዊ ወረራዎች ኢኮኖሚያዊ ወጪዎችን በተመለከተ ያሉ ወቅታዊ የዕውቀት ክፍተቶችን እናሳያለን። በመጨረሻም ጥናታችን የወረራ መከላከያ እርምጃዎችን ለማዘጋጀትና ተግባራዊ ለማድረግ እንዲሁም በብሔራዊም ሆነ ክፍለ-አህጉር ደረጃ የሚተገበሩ የተቀናጁ የድህረ-ወረራ መቆጣጠሪያ እርምጃዎችን ይደግፋል። በአፍሪካ ሀገሮች ውስጥ ያሉትን ውስብስብ ማህበራዊ እና ኢኮኖሚያዊ እውነታዎች ከግምት ውስጥ በማስገባት በአሁኑ ጊዜ ትኩረት ያልተሰጠው የሥነ-ሕይወታዊ ወረራዎች ችግር ለዘላቂ ልማት ጥቅም ቅድሚያ ሊሰጠዉ የሚገባ ጉዳይ ሊሆን ይገባል።

Abstract in Arabic

التكاليف الاقتصادية للغزو البيولوجي في أفريقيا: تهديد متنامٍ، لكن متجاهل؟ يؤثر الغزو البيولوجي بشكل كبير على النظم البيئية الطبيعية، وعلى المجتمعات البشرية. وعلى الرغم من أن المعرفة بالآثار الاقتصادية للغز البيولوجي توفر معلومات بالغة الأهمية من أجل تدبير ناجع وسياسات فعالة، إلا أن التوليفات الموثوقة لا تزال غير متوفرة. وينطبق هذا بشكل خاص على البلدان ذات الدخل المنخفض، حيث الموارد الاقتصادية غير كافية للسيطرة على آثار الغزو. اعتمدنا في هذه الدراسة على قاعدة بيانات InvaCost التي تم تطويرها مؤخرًا - وهي المستودع الأكثر شمولاً للتأثيرات المالية للأنواع الغريبة الغازية في جميع أنحاء العالم – من أجل إنتاج أول توليفة للتكاليف الاقتصادية للغزو البيولوجية في القارة الإفريقية. ولقد تبين أن التكاليف المبلغ عنها للغزو البيولوجي تراوحت بين 18,2 مليار دولار أمريكي و78,9 مليار دولار أمريكي ما بين عامي 1970 و 2020 ، ويمثل هذا عبئا اقتصاديا هائلا على البلدان الإفريقية التي لازالت تقلل من شأنه. كما أن المقلق في الأمر هو أن هذه التكاليف تتزايد بشكل كبير مع مرور الوقت، دون أي علامات على التراجع في المستقبل القريب. وكانت معظم التكاليف المبلغ عنها ناجمة عن الأضرار الناتجة عن الأنواع الغازية بدلاً من المصاريف المتكبدة من أجل التدبير. وتجدر الإشارة إلى أن الاتجاه هم بشدة مناطق قليلة (أي جنوب وشرق أفريقيا) وبعض قطاعات الأنشطة (أي الزراعة) وكبدها عدد قليل من الأصناف الغازية (أي ثلاث آفات حشرية بشكل أساسي: *Chilo partellus* و*Tuta absoluta* و *Spodoptera frugiperda*). كما نسلط الضوء أيضًا في هذه الدراسة على الفجوات الكبيرة والحاسمة في المعرفة الحالية حول التكاليف الاقتصادية للغزو البيولوجي التي لا تزال بحاجة إلى سدها من خلال المزيد من الجهود البحثية الواسعة النطاق والإجراءات الإدارية في جميع أنحاء القارة. وفي الأخير، تقدم دراستنا الدعم لوضع وتنفيذ تدابير وقائية فضلا عن إجراءات إدارية متكاملة بعد الغزو على الصعيدين الوطني والإقليمي.

Abstract in Bamanan Kan

Ɲanamaya finkuraw bɛsekakɛ nɔdyateminɛ taye kungo lahalaw ni sigida lahalaw kan. Alini ayasɔrɔ dɔniya minu bɛ talikɛ ɲanamaya finkuraw cyarili musakakola, ka kunafoni nafamaw jira, ka kɛɲɛ ni maralifɛrɛw ani gilancyoko jonjonw ye, alisa tɔbujɛ. o sɛbɛtyaledo dyamana kono minu ka sɔrɔ ka dɔkɔn, ani u ka nafasɔrɔ finw dɔkɔya kaman, utese ka ɲanamaya finkuraw cyarili kɔlɔsi ani ka dansigi u yɛlɛma cyogola. Nin ɲinini kɔnɔnana anyan sinsin kunafoniwkan min bɔra "InvaCost" la. U ka kunafoniw ye finyé min ni mɔgɔ beseka isinsin akan ɲanamaya finw sɔrɔko kunkan ani finsukuya wɛrɛ min bɛ bɔ dunya fanwɛrɛ fɛ ka dunya minɛ. Kunafoni minu bɛ talikɛ "IvanCost" la u sɛbɛntyala wakati labanw na. Nin bara nunu kɛra sababuye ka dyabi fɔlɔ sinsinlenw sɔrɔ minu bɛ talikɛ ɲanamaya finkuraw musaka kola farafina marabolokan. An ya dyateminɛ ko musaka minuw dantikɛla kakɛɲɛ ni fin nunu yariliye, o ba daminɛ Ameriki wari dolari milyari 18,2 ka ta bila 78,9 ka bɔ san 1970 ka na bila 2020. Nin bɛ musaka cyanma kofɔ, ŋa minuw dyatelentɛ farafina dyamanaw bolo. Dabaliban kowɛrɛ tuguni, nin musakanunuw bɛtaka cyokoyala min ka telin, ka kɛɲɛ ni wagatiye, kasɔrɔ u jigini fɛrɛ foyi yiralentɛ. Musaka minu bɔrama, okun dɛnendo bakurubala minu bɛ talikɛ kɔlɔlɔwla minu bɛ talikɛ fin nunuw cyaribawla katɛmɛ musakako min dyalatikɛlendo labarali kama. Sika kun kɛlendo o famuyali bolonina marayɔrɔ damadɔ fanfɛ minu bɛ farafinakɔnɔ ani cyakɛda bolowla (sɛnɛ bo la) min bara tun geleyalendo fɛɲɲanamanw fɛ (inafo finsaba hakɛ: Chilo partellus, Tuta absoluta, Spodoptera frugiperda). An ba yira fana ka fɔ ko dɔnya minunw beye sisan ɲanamaya finw cyarili musaka kowkan, ko belebele be u dyɛ minuw kakan ka dafa ni ɲinininw ani waleya waralenw ye farafina fantyama na. Kuntyɛlila anka ni ɲinini bɛnakɛ dɛmɛ ye fɛrɛkunbɛnanw ani waleya minuw bɛ talikɛ kɔlɔlɔwla minuw dɛn nendo fin nunuw cyarilila ka kɛɲɛ ni marayɔrɔw ye. Ka da farafina jamanaw sigida ni a musakakow gɛlɛyakan, gɛlɛya min bɛyen bi na jatelen tɛ kakɛɲɛ ni ɲanamaya finw cyarili ye, o kan ka kɛ bɛ kunkelena ye, yiriwa badabada kama.

Abstract in French

Les coûts économiques des invasions biologiques en Afrique: une menace croissante mais négligée ? Les invasions biologiques peuvent avoir un impact considérable sur les écosystèmes naturels et les sociétés humaines. Cependant, bien que les connaissances sur les impacts économiques des invasions biologiques fournissent des informations cruciales en termes de gestion, des synthèses récentes et fiables font encore défaut. Cela est particulièrement vrai pour les pays à faible revenu où les ressources économiques sont insuffisantes pour contrôler les effets des invasions. Dans cette étude, nous nous sommes appuyés sur la base de données "InvaCost" développée récemment - le référentiel le plus complet sur les impacts monétaires des espèces exotiques envahissantes dans le monde - pour produire la première synthèse des coûts économiques des invasions biologiques sur le continent africain. Nous avons constaté que les coûts déclarés des invasions varient entre 18,2 milliards de dollars américains (USD) et 78,9 milliards USD entre 1970 et 2020. Cela représente une charge économique énorme, mais encore très sous-estimée, pour les pays africains. Plus alarmant encore, ces coûts augmentent de façon exponentielle au fil du temps, sans aucun signe de réduction pour les années à venir. Les coûts reportés étaient principalement (*i*) dus aux dommages causés par les envahisseurs plutôt qu'aux dépenses engagées pour lutter contre leurs invasions, (*ii*) fortement biaisés vers quelques régions (Afrique australe et orientale) et secteurs d'activité (agriculture) et (*iii*) associés à un nombre restreint de taxons envahissants (essentiellement trois insectes ravageurs: *Chilo partellus*, *Tuta absoluta*, *Spodoptera frugiperda*). Notre étude met également en lumière de cruciales lacunes dans les connaissances actuelles sur les coûts économiques des invasions qui doivent encore être comblées par des efforts de recherche et des actions de gestion plus importants et étendus à travers le continent. Enfin, notre travail souligne la nécessité de l'élaboration et la mise en œuvre de mesures préventives pour empêcher l'introduction des espèces envahissantes, ainsi que l'intégration des actions de gestion aux niveaux national et régional. Compte tenu des réalités sociétales et économiques complexes des pays africains, le problème actuellement négligé des invasions biologiques devrait être une priorité pour le développement durable.

Abstract in Haussa

Ɗaukar nauyin mamayar ƙwayoyin halittu a Afirka : wata barazana mai yaɗuwa amma da aka yi wa kamun sakainar kashi ? Yaɗuwar ƙwayoyin halittu (tsirai ko ƙwari) na iya samun babban tasiri a kan muhalli da al'umomi. Sai dai, ko da yake ilimi da ake da shi a kan tasirin yaɗuwar ƙwayoyin halittun a kan tattalin arziki na bayar da muhimman bayanai don ingantuwar siyasa da gudanarwa, amma amintattun bayanai sun faskara. An fi ganin zahirin hakan musamman a ƙasashe masu raunin tattalin arziki da ba su iya fuskantar lamarin. Cikin wannan binciken, mun yi amfani da rumbun bayanai na InvaCost da aka bunƙasa kwanan nan- kafa mafi cika da inganci a kan tasirin kuɗaɗen da

akan kashe don fuskantar zaukakkin ire-iren ƙwayoyin halittu masu mamaya a faɗin duniya- domin samar da amitattun bayanai a kan kuɗin da ake kashewa ta fuskar mamayar kwayoyin halittu a nahiyar Afirka. Mun gano cewa kuɗaɗen da aka bayyana cewa an kashe da ga shekara ta 1970 sun kai biliyan (miliyar) 18,2 dalar Amerika zuwa biliyan 78,9 a shekara ta 2020.

Wannan wani babban nauyi ne a kan tattalin arzikin ƙasashen Afirka, amma da ba a mizanta da kyau ba. Abu mafi ɗaga hankali kuma shi ne: kashe-kashe kuɗaɗen ƙaruwa yake yau da gobe, ba tare da wata alama ta raguwa ba. Kuɗaɗen da aka bayyana an kashe sun shafi musamman ɓarnar da masu mamayar suka yi, maimakon kashe su ta fuskar gudanar da aiki.

Wannan manufar ta sami komabaya sosai a wasu sassan Afirka (wato sashen kudu na Afirka da gabashin Afirka) da wasu ɓangarorin aiki (wato noma) kuma hakan na da nasaba da wasu ƴan tsirarun irin ƙwayoyin halittu masu mamaya (wato musamman ƙwaro uku maɓarnata albarkatun noma : *Chilo-partellus*, *Tuta absoluta*, *Spodoptera frugiperda*).

Muna kuma jan hankali a kan manyan kura-kurai cikin bayanan da ake da su a halin yanzu da suka shafi ɗaukar nauyin mamayar ƙwayoyin halittu, da ya kamata a magance su ta hanyar ƙoƙarin bincike da faɗaɗa gudanar da ayyuka ko'ina cikin nahiyar.

A ƙarshe, bincikenmu na goyon bayan ɗaukar matakan riga kafi da kuma na gudanar da aiki bayan wanzuwar mamaya a matakin ƙasa da ma na ƙasa da ƙasa. Da la'akari da zahirin yanayin tattalin arziki da rayuwar al'umar ƙasashen Afirka mai sarƙaƙƙiya, ya kamata matsalar mamayar ƙwayoyin halittu da ke gudana a halin yanzu, ta zama a sahun gaba don cimma cigaba mai ɗorewa.

Abstract in Malagasy

Ny totalim-bidy ara-toekarena noho ny fananiham-bohitra biolojika ao Afrika : tsindry tsy mitsaha-mitombo nefa atao tsirambina ? Ny fananiham-bohitra biolojika dia mety hisy fiatraikany lehibe amin'ny tontolo iainana voajanahary sy ny fiarahamonin'ny olombelona. Na dia manome fahalalana betsaka momba ny politika sy ny fitantanana mahomby ny fampahalalana ny voka-dratsy ara-toekarena noho ny fananiham-bohitra biolojika, dia mbola tsy ampy ireo fandravonana azo antoka. Hita taratra izany eo amin'ireo firenena ambany fidiram-bola izay tsy manana ny ampy hifehezana ny vokadratsin'ny fananiham-bohitra. Amin'ity fandinihana ity dia mifototra amin'ny angon-drakitra InvaCost vao novolavolaina tsy ela - ny firaiketana feno kokoa momba ny fiantraika ara-bola ny vokatry ny karazan-javamananaina vahiny mpandrakotra manerantany – mba hamokarana ny fandravonana dingana voalohany ny vidimpiainana noho ny fanafihana biolojika ao amin'ny kaontinanta afrikanina. Tsikaritray fa ny vola lany tamin'ny fananiham-bohitra biologika dia 18,2 miliara $ ka hatramin'ny 78,9 miliara $ teo anelanelan'ny 1970 sy 2020. Fahavoazana lehibe ho an'ny toe-karena izany, nefa dia ambany ny tombatombana ho an'ny firenena afrikanina. Mbola anisan'ny mampatahotra ihany koa ny amin'ireo totalim-bidy ireo izay tsy mitsaha-mitombo hatrany ary tsy misy ny fambara ny amin'ny fihenany. Ny totalim-bidy voalaza dia miompana indrindra amin'ny fahasimbana naterak'ireo mpandrakotra fa tsy ny fandaniana amin'ny fitantanana. Ity fironana voalaza ity dia nitanila tamin'ny faritra vitsivitsy (izany hoe aty amin'ny faritra Afrika atsinanana sy atsimo) sy seha-pikatrohana manokana (izany hoe ny fambolena) ary eo ihany koa ny havitsian'ny karazana mpandrakotra (izany hoe niompana kokoa amin'ireo bibikely mpandrava: *Chilo partellus*, *Tuta absoluta*, *Spodoptera frugiperda*). Tianay ho marihina ihany koa ny tsy fahampiana lehibe eo amin'ny fahalalana momba ny vola lany amin'ny fananiham-bohitra amin'izao fotoana izao izay mbola mila jerena akaiky amin'ny alàlan'ny ezaky ny fikarohana bebe kokoa sy ny hetsika fitantanana manerana ny kaontinanta. Ary farany, ny fandinihanay dia manohana ny famolavolana sy ny fampiharana ny fepetra fisorohana ary koa ny hetsika fitantanana aorian'ny fananiham-bohitra amin'ny sehatra nasionaly sy isam-paritra. Raha ny zava-misy eo amin'ny fahasarotan'ny fiainana ara-piaraha-monina sy ara-toekarena eo amin'ny firenena afrikanina, dia tokony hatao laharam-pahamehana amin'ny fampandrosoana maharitra ny olan'ny fanafihana biolojika amin'izao fotoana izao.

Abstract in Portuguese

Os custos econômicos das invasões biológicas na África: uma crescente, mas negligenciada ameaça? Invasões biológicas podem impactar ambientes naturais e sociedades humanas dramaticamente. No entanto, embora o conhecimento dos impactos econômicos das invasões biológicas forneça uma visão crucial para gestão e políticas eficientes, ainda faltam sínteses confiáveis. Isso é particularmente importante para países com pouca renda, onde recursos econômicos são insuficientes para controlar os efeitos das invasões biológicas. Nesse estudo, nós contamos com o banco de dados recentemente desenvolvido InvaCost – o repositório mais abrangente sobre os impactos financeiros das espécies invasoras em todo o mundo – para produzir a primeira síntese dos custos das invasões biológicas no continente Africano. Nós encontramos que o custo reportado das invasões variou entre 18,2 bilhões de dólares e 78,9 bilhões de dólares, dados de 1970 a 2020. Esse valor representa uma enorme, apesar de subestimada, carga econômica para os países Africanos. Ainda mais alarmante, esses custos crescem exponencialmente com o tempo e sem nenhum sinal de redução no futuro próximo. Os custos reportados foram direcionados principalmente por danos causados pelas espécies invasoras, mais que pelas despesas devido ao manejo. Essa tendência foi altamente enviesada para algumas regiões (tais como, África Austral e Oriental) e setores de atividade (tal como, agricultura), e gerada por um pequeno número de taxa invasores (tais como, três insetos-pragas: *Chilo partellus*, *Tuta absoluta*, *Spodoptera frugiperda*). Nós também destacamos grandes lacunas no atual conhecimento sobre os custos econômicos das invasões biológicas, que ainda precisam ser superados com mais esforços de pesquisa e ações de manejo em todo o continente. Finalmente, nosso estudo fornece suporte para o desenvolvimento e implementação de medidas de prevenção, assim como ações de manejo integrado pós-invasão em escala nacional e regional. Considerando a complexa realidade social e econômica do continente Africano, o problema atualmente negligenciado das invasões biológicas deve se tornar uma prioridade para o desenvolvimento sustentável.

Abstract in Puular

Ko ruudooji mbarakoñ ngarkoñ e Afrik ngardata : bonere mawnde nde reentaaka ? Ruudooji mbarakoñ na mbaawi adude bonere mawnde e kala windere e nguurndam yimbe. Kono, ko gonggo gandal nowoodi faade ko deen bonne ngadorta ko hadatapolitik e jogogal peewngal. Duumdoon tengtikoyleydeele pamdude doole de koomkoomeeji mum en njonaani ngam reentude bonere diin ruudooji. E ndeer nde windere, baariden koy ligeey « InvaCost » tiaraado ko booyaani - liggeey burdo timmu faade e bonere jawdi leyyi niembaadi jaaknudi aduna – ngam yaltinde fibre idiinde holliroore ko diin ruudooji ngadata e leydi Afrik. En njii wonde diin ruudooji edi mbonna hakkunde 18[2], miliaaruji dolaar e 78,9 dolaar ko fuddori hitande 1970 faade hitannde 2020. Duumko baasal mangal, kono ngal limaaka, e ndeer Afrik. Ko buriko hulbinaade woni bonere ndeni besdo no feewi niande fof, ko adata ustaare yiaaka… Ko adiiko bonere nde no fawondira umiiko e ruudooji he wona e ko wadaako e ngaynaaka.Duumdoon firti no feewi ko e woon nokkuuji e woon ligiyaaji (woni ndemri) tawa adi dum ko seeda e woon ruudoooji : "*Chilo partellus*, *Tuta absoluta*, *Spodoptera frugiperda*". Min kolira kadi waasde gandal nofeewi faade e ko di ruudooji mbonanta e danialmen adanimen fotde tinnaade e witto e neende diawdimen e ndeer Afrik.

Ko watindiiko, jangde men teengtini fotde tinnaade ardinde peeje et bade tiagal ruudooji e ndeer leydimen e ko taariindi ko. Si en ndaari aadaaji men e koomkoom mettudo mbo leydeele afrik, itude tiadeele hande umiidi e ruudooji potden ardinde ngam ndanien ngartam booydam.

Abstract in Spanish

Los costos económicos de las invasiones biológicas en África: ¿una amenaza creciente pero desatendida? Las invasiones biológicas pueden impactar dramáticamente los ecosistemas naturales y las sociedades humanas. Sin embargo, aunque el conocimiento de los impactos económicos de las invasiones biológicas proporciona información crucial para una gestión y política eficientes, todavía faltan síntesis fiables. Esto es particularmente cierto para países de bajos ingresos donde los recursos económicos son insuficientes para controlar los impactos de las invasiones. En este estudio nos basamos en la base de datos

InvaCost, la cual ha sido desarrollada recientemente y constituye el repositorio más completo sobre los impactos económicos de las especies exóticas invasoras a nivel mundial, para producir la primera síntesis de los costos económicos de las invasiones biológicas en el continente Africano. Descubrimos que los costos reportados de las invasiones oscilaron entre US$ 18.2 mil millones y US$ 78.9 mil millones entre 1970 y 2020. Esto representa una carga económica masiva, pero muy subestimada, para los países africanos. Lo que es más alarmante es que estos costos están aumentando exponencialmente con el tiempo, sin mostrar signos de disminución en el futuro cercano. Los costos reportados corresponden principalmente a daños causados por las invasiones, en lugar de a gastos de gestión. Esta tendencia está sesgada hacia unas pocas regiones (África meridional y oriental) y sectores de actividad (agricultura) y resulta de un pequeño número de taxones invasores (principalmente de tres plagas de insectos: *Chilo partellus*, *Tuta absoluta* y *Spodoptera frugiperda*). También destacamos grandes lagunas en el conocimiento actual sobre los costos económicos de las invasiones que deben superarse con esfuerzos de investigación y acciones de gestión más generalizadas en todo el continente. Finalmente, nuestro estudio brinda apoyo para el desarrollo e implementación de medidas preventivas, así como acciones integradas de manejo post-invasión a nivel nacional y regional. Teniendo en cuenta las complejas realidades sociales y económicas de los países africanos, el problema actualmente desatendido de las invasiones biológicas debería convertirse en una prioridad para el desarrollo sostenible.

Abstract in Tamasheq

Alquyuman daɣ awa deqalan emel in almissibaten tin-issudar daɣ Afrik: almissibat tətiiwaḍat mušen war-hin nitawajrah? Almiṣṣibaten tin - issudar adobatnat ad- ilanat takmo maqqorat fil awad eqalan ahinzazaɣ d- timuzdoq n-adinat. Hakid-ijja awendaɣ, kud daɣass imiyiišãn d-musnaten idaqqalnen terk-erché tad-d- tirəwnát almaṣṣibaten ti ikmanen usudar d-ahinzazaɣ, harat wendaɣ kudaɣ amoss ayihakan issalan assoxatnen yi manaɣafan hakid daɣ adabara iwir sarho, hakid ijjawendaɣ wirid inšeš har harwa ayinfan harat.

Harat wendaɣ eqal tidit hulen y-iduwilan wi arkamnén id filas iduwilan windaɣ ibraran hulen daɣ awadeqalan aššujiš in azrəf iškam diš ad- ajjin iniyat yi haratan wi did tiruwnat almaṣṣibaten.

Daɣ taɣare tadaɣ nasihatal fil issalan id išreynen hanaɣid ifalnen awass itawan Inva Cost- ɣas teɣare ten təmoss almintal assoxen daɣ awadeqalan tikmawen meɣ tinfawen in izirfan fil mudaran wi taqalnen almiṣṣibaten daɣ udunia- tə mušɣult ten daɣ kul wir təga ar-yadid tissaɣsil meɣ adid tišinšiš alquyuman daɣ azrəf n almaṣṣibaten ti ikmanen issudar daɣ afriq.

Nijrahin as alquyuman witawassaneen n- almaṣṣibaten ilanant jər 18,2 in milliards USD d- 78,9 milliards USD jər awattay wan 1970 har wan 2020. Awen eqal aẓuk maqqoran daɣ azzruf, hakid-ijjawendaɣ aẓuk wendaɣ atiwalka y i iduwilan win Afriq. Hakid-ijja awendaɣ awa assharahaɣan harwa as alquyuman windaɣ tiwaḍan hak awattay, sas wartila aššamol nas fanzan. Ilquyuman windaɣ attwana ijjan daɣ šaɣšadan ɣas widid orawan almaṣṣibaten issilmadan as waden amašal ayija azrəf daɣ ijjin n-ewatel y almaṣṣibaten waladaɣ ikanan n ayinfan harat. Harat wadaɣ išrayan n iban kanan n išaɣil səmək olaɣan ijja hulen daɣ kalan iyaḍ n afrik (ilmintal ikalan n afrik wi ahanen teje tan agala d- win dinig) d išarajan n təmašɣolen(šund issuduma) hakid ijja awendaɣ marsalan windaɣ erawtanid harat in ilmissibaten in mudaran(imudaran windaɣ amosnen ilmissibaten ijjan daɣ karad šarajan n magadan witajinen šaɣšad : (Chilo partellus, Tuta absoluta, Spodoptera frugiperda). Nissilmad as ilant marsallan ajjotnen daɣ awadeqalan masnat in alquyuman in awaytajašan tabilant tajjat d- ilmissibaten, ɣas anihaja ad- ittiwitir adabara ijjan daɣ umaɣ d- əssimil in təmušɣult tolaɣat təlssat Afrik. Nissilmad ḍarat awen as teɣare tadaɣ tidhal assəmil d- ijji n adabaratan əmosnen ewatel hakidaɣ təmušɣult ibdadnen daɣ ijji n adabara dat assa n- ilmiṣṣibaten daɣ iddiwil hakid daɣ iddiwilan wiyaḍnen. Filas attiwassan attarex d timizdoq n addinant taẓikanẓarat daɣ kalan win afrik, almušaqat ta ti təlat ɣas warhin titawajraj ašilidaɣ təmoss tabilant d- almiṣṣibaten ti ikmanen issudar, tabilant ten-daɣ əntass as anhaja ad taqqal itus yəssəmil in effes illan taɣrist.

Abstract in Woloff

Tënk. Ruurum ndundat yi lu aay la ci yàq kéew-kéewaan yu bindare yi ak dundug nit ñi. Ci loolu nag, doonte xam-xam am na ci njeexital i ruurum ndundat ci wàllug koom-koom ba aw yoon tijjiku ngir man a saytu caytu gu am solo ak teg i polotig, waaye jarabu yu doy, yu amul benn laam-laame ; àggaguñu ca ba leegi. Loolu ci réew yu néew doole yi la rawatee nag ndax ñàkk njumtukaay ak alal ju ñu waggaree ruur moomu. Jarabu gii, ñi ngi ko sukkandikoo ci dayu InvaCost bi ñu defar bu yàggul – ndàmb li gën a yomb a nànd ngir xam jeexital i ray-donni doxandéem yi ci àdduna wërngal kapp ci wàllug koppar – ngir jëmmal jarabu gi njëkk ci kembaaru Afrig ñeel li ruurum ndundat di jur ci alal ci koom-koom mi. Gis nanu ne ruur mi, li ko dale 1970 ba 2020, bees ko nattee cig njëg ; toll na ci diggante 18.2 ba 78.9 tamndareet i US$. Alal ju bari jii di naaxsaay, luy nasaxal koomu réewi Afrig yi la. Li ci gën a doy waar, koom mu bari moomu ñuy ñàkk day yokk saa yu ne, te amul luy nuru ab dogal bees jël ngir saafara ko ci ëllag ju jampal. Alal jii ñu fésal nag mooy li ruur mi yàq waaye du lu ñu génne ngir saytug ruur mi. Yàqu-yàquy ruur moomu nag tane na ci yenn tund yi (i.e. Penku ak Bëj-déexu Afrig) ak ci yenn aaneer yi (i.e. mbay mi) boole ci lim bu néew ciy ndundat (taxa) ñoo fay ruur (i.e. ñatti gunóori ruurkat yi gën a ràññiku: *Chilo partellus*, *Tuta absoluta*, *Spodoptera frugiperda*). Gendiku nanu itam lu am solo, fi xam-xamu ruur mi tollandi ak alal ji miy laatul ci koom-koom, soxla na bu baax a baax ñu gën a yaatal góor-góorlu gi ci luññtu yi ak yokk jéego yi ci saytug ruur mi ci kembaar gi. Ngir teeral, sunu jarabu gii jur na cëslaay ngir samp ak fànnoo ay dogal yoo xam ne dinañu sóor nees di saytoo bir yi ginnaaw bu am ruur amee moo xam ci biir réew mi la mbaa ci tundi kembaar gi. Bees bàyyee xel ci ni dundiin wi nosoo ak tolluwaayi koom-koomu réewi Afrig yi, soobantal gii tembe ñu soobantal ruurum ndundat yi lu war a dakk la tey yitte ju jamp ngir ug suqliku gu sont te sax dàkk.

Abstract in isiZulu

Izindleko ezidalwa izimila nezilwanyana zokufika kwizwekazi laseAfrika: Ingozi ekhulayo kodwa enganakiwe. Isihloko esifingqiwe: Izindleko ezikhulayo kodwa ezingakaniwe zemizila nezilwanyana zokufika ezweni-kazi laseAfrika.

Izimila nezilwanyana zokufika zinomthelela omkhulu kwimvelo kanye nenhlalonhle yemiphakathi. Nakuba ukuqondisisa kahle imithelela yezimila nezilwanyana zokufika emnothweni kunikeza imininingwane ebalulekile ikakhulu uma kuzoliwa nokubhebhetheka kwazo kanye nokuhlaziya inqubomgomo yezomthetho, ulwazi olusemqoka noluthembekile lusashoda. Lokhu kuyiqiniso ikakhulukazi emazweni antulayo lapho umnotho ungenele ukuthi kubhekwane nemithelela yezimila nezilwanyana zokufika. Kulolucwaningo, sisebenzise isigcinalwazi iInvaCost esanda kusungulwa- lapho kugcinwe khona ucwaningo olubanzi noluphelele mayelana nemithelela yezimila nezilwanyana zokufika uma kukhulunywa ngomnotho emhlabeni jikelele- lesi sigcina lwazi sizosiza ukudalula izindleko ezivela ngenxa yokubhebhetheka kwezimila nezilwanyana zokufika ezwenikazi lase Afrika. Ngokusebenzisa lesi sigcina lwazi sithole ukuthi izindleko zokumelana nezimila nezilwanyana zokufika zilinganiselwa phakathi kuka $18.2 kuya ku $78.9 wezigidigidi zamadola aseMelika kusekela eminyakeni yo1970 kuya ku2020. Lokhu kutshengisa umthwalo omkhulu, kepha ongazakaze wacwaningwa ngokwanele wezomnotho emazweni ase-Afrika. Okuthusa kakhulu ukuthi lezi zindleko ziyakhula ngokuhamba kwesikhathi kanti futhi azikho izimpawu ezikhomba ukwehla kwazo esikhathini esizayo. Izindleko ezibikiwe zincike kakhulu kumonakalo owenziwa izimila nezilwanyana zokufika kunezindleko zokulwisana nokubhebhetheka kwazo. Lombiko ubususelwe kakhulu ezifundeni ezimbalwa (esizeNingizumu naseMpumalanga yeAfrika) kanye nasemikhakheni embalwa (isb. ezolimo) nakhona kubhekwe izibonelo ezimbalwa (ikakhulukazi izinambuzane ezintathu eziyinkathazo: Chilo partellus, Tuta absoluta, Spodoptera frugiperda). Siphinde siveze ukuntuleka kolwazi olwanele uma kukhulunywa ngezindleko zezomnotho ezidalwa yizo izimila nezilwanyana zokufika, nokusafanele kwenziwe ucwaningo olunzulu ukuze sizoqonda izindlela zokulwisana nokubhebhetheka kwazo ezwenikazi lonke lase Africa. Okokugcina, lolu cwaningo luhlanganiswe ngendlela yokuthi lukwazi ukweseka imizamo yokusungula izindlela ezizokuvimbela ukubhebhetheka kwezimila nezilwanyana zokufika emazingeni amazwe kanye nawezifunda.

Uma kubhekwa inhlalonhle kanye nezomnotho emazweni wonke ase-Afrika, lokhu kuntuleka kolwazi uma kukhulunywa ngezimila zokufika kumele kube yinto ebhekisiswayo ikakhulu uma kukhulunywa ngezentuthuko.

Keywords
Africa, agriculture, biological invasions, damage, economic costs, InvaCost, management

Palabras clave
África, agricultura, invasiones biológicas, daños, costes económicos, InvaCost, gestión

Trefwoorde
Afrika, landbou, indringer spesies, skade, ekonomiese koste, InvaCost, bestuur

ቁልፍ ቃላት
አፍሪካ; ግብርና; ሥነ-ሕይወታዊ ወረራዎች; ጉዳት; ኢኮኖሚያዊ ወጪዎች; ኢንቫኮስት; ቁጥጥር።

Sigiden bakurubaw
Farafina, sɛnɛ, Ɲanamaya finkuraw cyarili, kɔlɔlɔ, musaka, InvaCost, labarali

Mots-clés
Afrique, agriculture, invasions biologiques, pertes et dommages, coûts économiques, InvaCost, gestion

Waat yu am solo yi
Afrig, mbay, ruuri ndundat yi, yàqu-yàyu, njeexital ci koom-koom, InvaCost, saytu gi

Amagama angukhiye
Afrika, ezolimo, izimila nezilwanyana zokufika, umonakalo, izindleko zezomnotho, InvaCost, ukubhekana

Introduction

Biological invasions have become a worldwide problem because of the accelerating rate of globalization, particularly since the end of the 20th century due to increasing modern travel, trade and technology, and these factors are likely to intensify the spread of invasive alien species (IAS) (Seebens 2015; Seebens et al. 2019). Within the context of Africa, the increased threat and spread of IAS will be no exception given the continent's evolving travel and trade (Rouget et al. 2016; Faulkner et al. 2017; Faulkner et al. 2020). Despite the relatively low research effort in invasion biology in most African countries, IAS studied until now across the continent (e.g. 16% of the species currently listed in the Global Invasive Species Database, GISD; www.iucngisd.org/gisd/) represent important drivers of ecological disturbance (e.g. biodiversity loss; Zengeya et al. 2020), social and health issues (e.g. disease transmission and impact on water resources; Wild 2018; Ogden et al. 2019), and economic losses and expenses (e.g. reduction in the yield of agricultural crops; Pratt et al. 2017).

Some of these IAS can become invasive after their intentional introduction by humans. For example, the tree *Prosopis juliflora* was introduced in the Afar region (Ethiopia) for water and soil conservation, shade and wind protection, and as firewood, fencing and building material. *P. juliflora* soon invaded croplands, grasslands, riverbanks and roadsides in the area, reducing native biodiversity, grazing potential and water supply (Shiferaw et al. 2019). Another example is the invasion of the succulent plant *Opuntia stricta* in South Africa, where it was initially introduced as an ornamental plant. *O. stricta* is currently recorded as invasive across most of the country, reducing food production, causing loss of grazing potential, transforming habitats, altering native biodiversity and causing injuries to people due to its spines (Novoa et al. 2016a). The last example is the marbled crayfish, *Procambarus virginalis*, which was first observed in markets in Madagascar around 2005 where it continues to be sold as a valuable food source. *P. virginalis* rapidly became invasive, impacting endemic freshwater biodiversity, rice agriculture and local freshwater fisheries (Andriantsoa et al. 2020). In addition, many IAS can spread across the African continent following their accidental introductions by humans. Some illustrative examples include the fall armyworm, *Spodoptera frugiperda*, a voracious polyphagous pest from tropical and subtropical regions of the Americas which threatens several important crops in Western, Central and Southern Africa (Goergen et al. 2016); the house mouse (*Mus musculus domesticus*), black rat (*Rattus rattus*) and brown rat (*Rattus norvegicus*) that were introduced through seaports and can dramatically decrease the indigenous rodent fauna, increase zoonotic risk and impact food security for human populations (Diagne et al. 2017; Dossou et al. 2020); and the Asian mosquito (*Anopheles stephensi*), which represents a new malaria vector for about 126 million urban dwellers across Africa (Sinka et al. 2020).

These invasions do not show any signs of abatement in the near future (Seebens et al. 2017), and many species that are not yet recorded in Africa are predicted to invade the continent over the coming decades (Faulkner et al. 2020). Consequently, since invasions are a transboundary issue, managing invasions should be prioritized on this continent in a regional manner (Faulkner et al. 2017; Faulkner et al. 2020). However, despite the increasing knowledge of IAS distribution and impacts, biological invasions still remain relatively poorly studied in developing countries (Nghiem et al. 2013), particularly in Africa – with the exception of South Africa (van Wilgen et al. 2020). Yet, this information is crucial for identifying priorities, designing efficient policies and implementing optimal management actions at relevant scales (Latombe et al. 2017; Pagad et al. 2018). As such, understanding the magnitude of impacts of IAS across Africa is a critical step towards efficient mitigation.

Economic aspects are critical in this context, especially regarding the limited economic capacity of most African countries to counteract invasions. Indeed, information on the economic impacts of biological invasions is important at several levels, especially for (*i*) increasing societal awareness on the substantial losses caused by invasions and compelling policymakers to act on the short- and long-terms against the introduction, proliferation and spread of harmful invaders, (*ii*) designing efficient policies and implementing evidence-based decisions through both prioritization of targeted IAS and/or susceptible areas as well as pre-evaluation of measures (e.g. cost-efficiency analyses) and (*iii*) ensuring sustainable management actions according to the economic capacities of countries/regions (Born et al. 2005; Larson et al. 2011; Dana et al. 2013; Caffrey et al. 2014; Diagne et al. 2021). A consistent, broad-scale approach using economic impact data is essential for both research and management purposes (Diagne et al. 2020a). This can contribute to the development of collaborative programs and coordinated responses among countries. However, to the best of our knowledge, the African continent lacks such cost-synthesis. Until now, regional- or continental-scale data relating to the economic impact of invaders in Africa were only available for relatively few species (e.g. *Tuta absoluta*; Rwomushana et al. 2019), sectors (e.g., smallholder livelihoods; Pratt et al. 2017) and regions (South Africa; Wild 2018).

The recent advent of the "InvaCost" database (Diagne et al. 2020b) allowed us to address this limitation by providing the first general overview on the economic costs of biological invasions across the African continent. "InvaCost" is the first comprehensive compilation of the documented economic costs of IAS globally. This freely accessible and updatable catalog contains cost estimates extracted from scientific peer-reviewed articles and grey-literature sources, and covers most taxa, geographical regions and activity sectors worldwide. It thus provides unprecedented opportunities to comprehensively assess and understand the economic impacts of invasions at multiple spatial scales, particularly for Africa where such knowledge is usually poor and highly fragmented (Diagne et al. 2021). Here, we aim to (*i*) provide the first state-of-the-art study on the economic costs of biological invasions in Africa, (*ii*) decipher how these costs are distributed over space, time, taxa, activity sectors and types of costs, and (*iii*) discuss the implications of these costs for invasion research and management in African countries.

Materials and methods

Original data

We relied on cost data recorded in the "InvaCost" database, which is the most up-to-date, comprehensive, and harmonized compilation and description of economic cost estimates associated with biological invasions worldwide (Diagne et al. 2020b). "InvaCost" has been generated following a systematic, standardized methodology to collect information from scientific articles, grey literature, stakeholders and expert elicitation. Each source was checked for relevance and the cost information was collated and standardized to a common and up-to-date currency in the database (i.e. 2017 US dollars). Each cost entry was depicted by a range of descriptive fields pertaining to the original source (e.g. title, authors and publication year of the reporting document), spatial extent (e.g. location and spatial scale), temporal coverage (e.g. time range and period of estimation), estimation methodology (e.g. method reliability and acquisition method) and the nature of cost (e.g. type of cost and impacted sector). All methodological procedures and details for data search (e.g. literature review), collation (e.g. cost standardization), validation (e.g. method repeatability) and improvement (i.e. corrections and inputs) are described elsewhere (Diagne et al. 2020b, 2020c). This updatable and publicly available data resource provides an essential basis for worldwide research and policymaking targeting IAS (Diagne et al. 2020a).

Starting dataset

To get the most complete and up-to-date dataset of the reported economic costs attributable to biological invasions in Africa for the last fifty years (1970–2020), we used the most recent version of the "InvaCost" database (version 3.0; Diagne et al. 2020c). This updated database integrates and refines cost information (9,823 cost entries; 64 descriptive fields) from two other repositories generated in the frame of the broader "InvaCost" initiative (Diagne et al. 2020a), and which include cost data collected from multiple sources and languages throughout the world (Angulo et al. 2021). Using this latest version of "InvaCost" allows us to limit potential gaps in existing literature as well as common language biases due to the exclusive consideration of English in research (Haddaway et al. 2015; Konno et al. 2020; Angulo et al. 2021). Using successive filters in the descriptive fields of the database (i.e. "Geographic region" and "Country" columns), we identified and then extracted all economic costs which were exclusively associated with African countries. Therefore, any cost entry that concerned non-African territories located within African regions (e.g. La Reunion Island) was not considered. We carefully checked the data to correct or remove any potential mistakes or duplicated cost entries. Our final database (hereafter called "starting dataset") consisted of 696 cost entries (Suppl. material 1).

Expanded dataset

We homogenized our "starting dataset" so that each cost entry – realized over a single year, a period of less than a year, or a cost reoccurring over a series of years – corresponds to a single-year estimate, which is repeated over the number of years during which the cost occurred. For this purpose, we used the "expandYearlyCosts" function from the "invacost" package (Leroy et al. 2020) in R version 4.0.2 (R Core Team 2019). This operation allowed us to expand each cost entry over its actual or estimated duration time, which was derived from the difference between the first year ("Probable starting year adjusted" column) and the last year ("Probable ending year adjusted" column) of the recorded cost. Consequently, this process removed any cost entries occurring over an unspecified time period in the database. Nonetheless, this step was necessary to ensure accurate estimations of the cumulative and mean annual costs of invasions over time. The expanded version of our "starting dataset" contained 4,259 cost entries (Suppl. material 1).

Conservative subset

To ensure a realistic and conservative synthesis of cost estimates reported for Africa, we applied two successive filters to this "starting dataset" (Suppl. material 2). The filters used were based on the categories listed for a set of descriptive fields in the "starting dataset" (see Suppl. material 3 for a detailed description of the fields). First, we kept only “observed” costs (rather than “potential” costs, under the "Implementation" column); second, we retained only economic estimates classified as “high” reliability (rather than “low” reliability, under the "Method reliability" column). Subsequently, all cost estimates for the year 2020 were excluded since these estimates were “potential” and/or of “low” reliability. Our final dataset (hereafter referred to as the "conservative subset") contained 2,302 cost entries between 1970 and 2019 (Suppl. material 4).

Categorization of cost data

We categorized the cost data according to different descriptive fields (hereafter called “descriptors”) in our datasets. First, we grouped countries into the five geographical regions defined by the United Nations geoscheme for Africa (available at https://unstats.un.org/): “Western Africa”, “Southern Africa”, “Northern Africa”, “Middle Africa”, and “Eastern Africa” (the latter also includes countries in the Indian Ocean) (Suppl. material 5). Second, we considered information on the typology of the costs ("Type of cost merged" column) that groups each cost estimate under “damage” (i.e. economic losses due to direct and/or indirect impacts of invaders, such as yield losses, damage repair, medical care, infrastructure alteration or income reduction); “management” (i.e. economic resources allocated to actions that aim at avoiding the invasion or dealing with more or less established invaders, such as prevention, control, research, eradication, education or mitigation policies); or “mixed” (i.e. when a single cost simultaneously includes both “damage” and “management” components) category (Suppl. material 6). Third, we determined which sectors were impacted by the reported costs (using information from the "Impacted sector" column); cost estimates that were not allocated exclusively to a single sector were classified under the “mixed” category. Fourth, economically harmful species were classified into different major ‘organism types’ based on information from the "Kingdom", "Phylum", "Class" and "Environment" columns: “Animalia” (i.e. insects, mammals, birds), “Plantae” (i.e. aquatic plants, terrestrial plants, semi-aquatic plants), and “Virus”. For each descriptor, cost estimates that could not be unambiguously and exclusively assigned to one category were labelled as “diverse/unspecified”.

Data analyses

Our purpose was to draw a complete, as well as a robust picture of the cost of biological invasions throughout the African continent. We used the following R packages - ggplot2 (v.3.3.2, Wickham 2011), rnaturalearthdata (v.0.1.0, South 2017) and networkD3 (v.0.4, Allaire et al. 2017) – to generate an array of graphical representations for each descriptor of interest.

First, we used the "starting dataset" to describe the full cost information that was available. To do this, we investigated how individual cost estimates and their source materials (i.e. peer-reviewed articles and grey literature) were distributed over time. We focused on both the number of cost estimates and the total costs accumulated between 1970 and 2020. The latter was obtained by summing all cost estimates provided in the "cost estimate per year 2017 exchange rate" column of the expanded version of the "starting dataset" (Suppl. material 1). We systematically distinguished the proportions of the cost estimates that were of “high” versus “low” reliability, as well as those that were actually realized (i.e. “observed”) or just merely predicted (“potential”).

Second, we used the "conservative subset" to investigate how the cost amounts were distributed across geographic regions, types of costs, impacted sectors and taxonomic groups for the period 1970–2019. Finally, we investigated the trend of costs over time using two strategies.

The first strategy included an estimation of both the cumulative costs incurred between 1970 and 2020 (i.e. the sum of all cost estimates provided in the "cost estimate per year 2017 exchange rate" column of the expanded subset; Suppl. material 4) and the mean cost amount for each decade over the same period (i.e. obtained by dividing the total cost of each decade by ten years).

The second strategy consisted of modelling the long-term trends in economic costs of invasions by fitting models of annual costs as a function of time. Indeed, a reliable estimation of the average annual costs over time should take into account (*i*) the dynamic nature of costs, (*ii*) the time lags between the real occurrence of the costs and their reporting in the literature (called ‘publication delay’ hereafter), (*iii*) the heteroscedastic and temporally auto-correlated nature of cost data, and (*iv*) the effects of potential outliers in the cost estimates. For this purpose, we implemented the "costTrendOverTime" function ("invacost" package; Leroy et al. 2020) on the $\log_{10}$-transformed cost estimates per year, which allowed modelling the trend of costs over time with a range of linear and non-linear modelling techniques while enabling a comparison of the respective outputs of all models generated. As statistical intricacies inherent to econometric data did not allow for a priori identification of the most relevant modelling technique to apply, we relied on ‘ordinary least squares regressions’ (linear, quadratic), ‘robust regressions’ (linear, quadratic - R package "robustbase", Maechler 2020), ‘multiple additive regression splines’ (MARS, R package earth, Milborrow 2017), ‘generalised additive models’ (GAM, R package "mgcv", Wood and Wood 2015) and ‘quantile regressions’ (quantiles 0.1, 0.5, 0.9, R package "quantreg", Koenker 2019). To optimize model performance, all models were calibrated following a robust linear regression using cost data as the response variable and time as a predictor, which allowed to identify obvious outliers in the years of cost occurrence. To account for potential data incompleteness due to the ‘publication delay’, we excluded from model calibration all cost estimates from 2014 onwards because they constituted obvious outliers with a sudden drop of two orders of magnitude. We confirmed these outliers by investigating robust regressions calibrated on all data, which had set the weights of years above 2013 near to zero (Suppl. material 7). Model discussion was based on the assessment of the predictive performance across models (Root-mean-square deviation, RMSE) as well as the goodness-of-fit measure (variance explained). Moreover, combining these diverse modelling procedures offers strong support for the observed temporal trends and provides consistent model outcomes. As this approach is highly data-demanding, we only applied it to the African continent without disentangling types of costs, regions, sectors or taxonomic groups.

Results

Overview of cost data available in the starting dataset

During the 1970–2020 period, economic costs associated with biological invasions in Africa were obtained separately for 33 countries (i.e. 4 from Middle Africa, 3 from Northern Africa, 3 from Southern Africa, 10 from Western Africa, and 13 from Eastern Africa; see Suppl. material 5 for further details). The expanded dataset contained 4,259 cost estimates collected from 103 source documents from both the grey (n = 39) and scientific peer-reviewed (n = 64) documents (Suppl. material 1). Except for sixteen documents that were written in French, all reporting documents used English as the primary language. This shows a clear language bias despite all efforts made for collecting cost information reported in 15 languages in the updated "InvaCost" database (version 3.0; Diagne et al. 2020c). We also showed that since the 1970s, the number of both the cost estimates and source documents steadily increased over the years, along with the total estimated cost amounts (Figure 1). This is despite a slight decline in the number of cost estimates over the last decade, which might be the result of a time lag between the occurrence of the most recent costs and when they were reported in the literature (Figure 1).

About 86% of the cost entries (n = 3,653) collated were only incurred in Southern Africa (Table 1; Figure 2). Far behind, Eastern and Western Africa were the most represented regions, with 287 (7%) and 155 (3%) cost estimates, respectively. These patterns are influenced by a small number of countries with cost entries in each region (Suppl. material 5). Within Southern Africa, South Africa reported the majority of costs (together, the two other countries within this region, Lesotho and Swaziland, were only associated with 33 of the 3,653 cost entries recorded); more than 60% of the costs recorded in Eastern Africa were associated with three of the ten reporting countries (i.e. Kenya, n = 71; Uganda, n = 48; Tanzania, n = 53); and costs recorded in Western Africa mostly concern Benin (n = 78). The other regions harbored fewer than 15 cost entries, with Middle Africa reporting the smallest number of cost data (n = 6). Cost estimates associated simultaneously with two or more countries belonging to (at

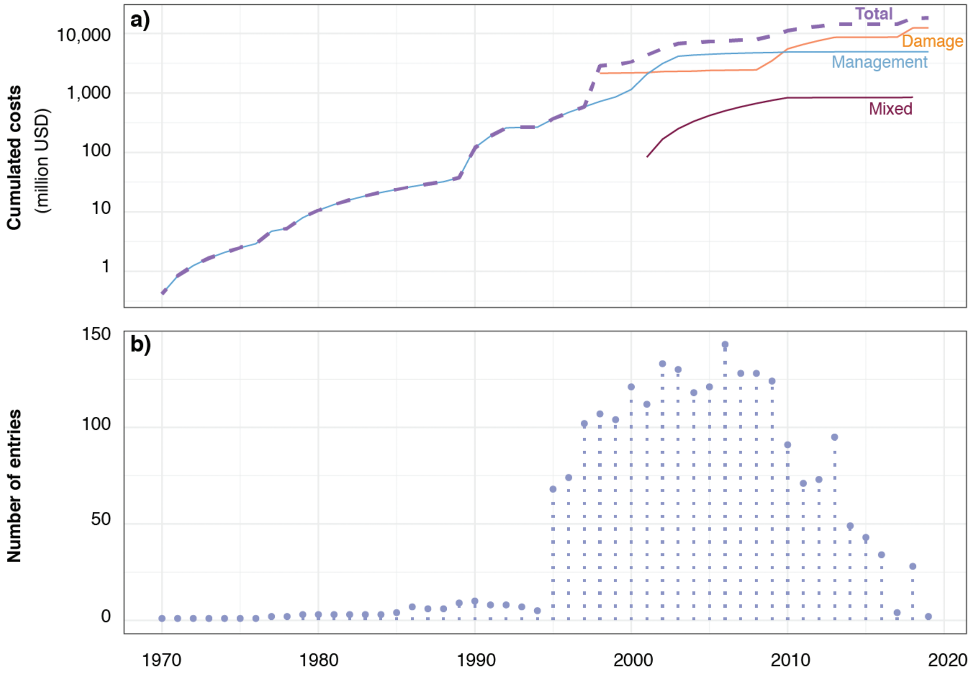

Figure 1. Distribution of cost estimates over time represented by **a** the cumulative cost amounts and **b** the number of cost entries per year between 1970 and 2019. We considered the expanded version of the *starting dataset*. In **a** the dashed line corresponds to the total amounts over the complete period, while the other lines correspond to the amounts of damage losses, management expenditures and mixed costs (i.e. when costs could not be exclusively associated with 'damage' or 'management' type).

least) two distinct regions (i.e. "diverse/unspecified" category) consisted of 146 cost entries (3%) in the "starting dataset".

Except for Southern Africa and "diverse/unspecified" regions, more than two thirds of the recorded cost estimates were considered as having been empirically observed in each region (Figure 2; Suppl. material 8). Conversely for Southern Africa and "diverse/unspecified" regions, respectively about 42% and 66% of the reported data comprised potential costs. Given that Southern Africa is the most represented region in our dataset, this means that a substantial portion of the cost estimates recorded throughout the continent (n = 1,807 out of 4,259) were derived from extrapolation or modelling approaches rather than true observations (Figure 2; Suppl. material 8). Finally, the reported cost data mostly exhibited a high degree of method reliability (Figure 2; Suppl. material 8). Indeed, the proportion of cost entries resulting from highly reliable cost estimations range between 75% (for Northern Africa) and 98% (for Eastern Africa), suggesting that most cost estimates were obtained from relevant estimation methodologies (Figure 2; Suppl. material 8).

Considering all cost entries in our "starting dataset", the accumulated cost of IAS in Africa reached a total of US$ 78.9 billion between 1970 and 2020 (see Table 1 for a detailed cost breakdown by region, taxa, sector, and type of cost).

Table 1. Quantitative summary of the cost data and estimates considered in this study for the African continent and each geographic region. Total cumulative costs (between 1970 and 2020) are provided in 2017-equivalent US$ million using both the *starting dataset* (*'Full' cost*) and *conservative subset* (*'Robust' cost*). Impacted sectors and type of cost are defined in the Suppl. material 3 (fields *Impacted sectors* and *Type of cost merged*). *N* represents the number of cost entries in the datasets (i.e. *starting dataset* and *conservative subset*); in the *Category* column, N corresponds to the number of original and expanded cost entries in the datasets considered – respectively the *starting dataset* and the *conservative subset*.

Descriptive field	Category	Africa		Eastern Africa		Middle Africa		Northern Africa		Southern Africa		Western Africa		Mixed	
		Full' cost (*N= 4,259*)	*Robust' cost* (*N= 2,302*)	*Full' cost* (*N=287*)	*Robust' cost* (*N=169*)	*Full' cost* (*N=6*)	*Robust' cost* (*N=3*)	*Full' cost* (*N=12*)	*Robust' cost* (*N=5*)	*Full' cost* (*N=3,653*)	*Robust' cost* (*N=1,980*)	*Full' cost* (*N=155*)	*Robust' cost* (*N=98*)	*Full' cost* (*N=146*)	*Robust' cost* (*N=47*)
Impacted sector	Agriculture	34209,41	8772,82	7189,47	6771,03	267,96	267,96	147,16	0,00	24,00	–	1740,11	1733,83	24840,72	–
	Authorities-Stakeholders	20710,11	4406,07	50,50	28,64	0,10	0,01	593,04	196,53	19028,77	3701,59	460,45	401,74	577,24	77,56
	Environment	17029,18	3277,03	–	–	–	–	–	–	17029,18	3277,03	–	–	–	–
	Fishery	0,36	0,36	–	–	–	–	–	–	–	–	0,36	0,36	–	–
	Forestry	22,29	0,10	–	–	–	–	–	–	0,11	0,10	–	–	22,19	–
	Health	2,20	2,20	2,20	2,20	–	–	–	–	–	–	–	–	–	–
	Mixed	6974,88	1744,35	613,83	10,09	1,80	–	–	–	1149,93	856,69	–	–	5209,33	877,56
	Public and social welfare	0,43	0,14	0,42	0,14	–	–	–	–	–	–	0,00	0,00	–	–
Type of cost	Damage_costs	56739,68	12418,47	7797,90	6773,37	269,76	267,96	147,16	0,00	17245,33	3216,81	2122,70	2116,41	29156,84	43,93
	Management_costs	21280,73	4937,90	45,47	25,68	0,10	0,01	593,04	196,53	19986,66	4618,62	78,23	19,52	577,24	77,56
	Mixed_costs	928,45	846,69	13,05	13,05	–	–	–	–	–	–	–	–	915,40	833,63
Taxon	Animalia	39016,50	7954,63	5666,22	4829,41	269,76	267,96	740,19	196,53	2,56	–	1813,99	1749,55	30523,78	911,19
	Plantae	38093,54	8636,73	435,20	373,05	0,10	0,01	–	–	37227,38	7833,37	386,94	386,38	43,93	43,93
	Viruses	1754,93	1609,57	1754,93	1609,57	–	–	–	–	–	–	–	–	–	–
	Diverse/Unspecified	83,89	2,13	0,07	0,07	–	–	–	–	2,05	2,05	–	–	81,76	–
Total costs for Africa and each region		78948,86	18203,06	7856,42	6812,10	269,86	267,96	740,19	196,53	37231,99	7835,42	2200,92	2135,93	30649,48	955,12

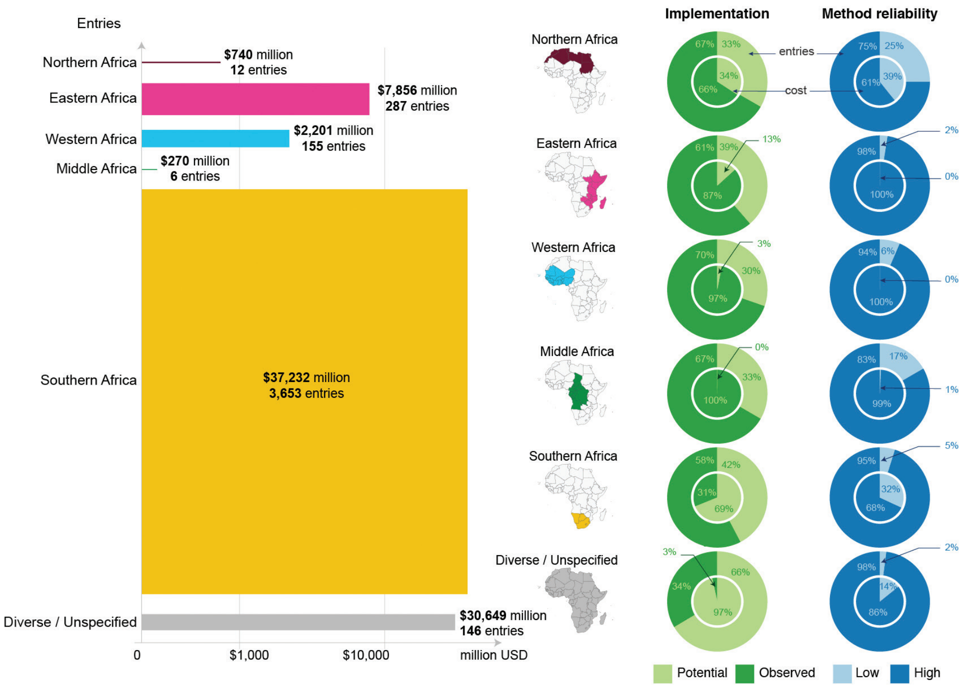

Figure 2. Typology and distribution of costs (number and estimates) recorded in the *starting dataset* according to their reliability ("high" *versus* "low") and their implementation ("potential" *versus* "observed"). We present both cost figures (total cumulative costs in 2017-equivalent US$ million for 1970–2019) and number of expanded cost entries as well as their specific proportion for each official region. *Implementation* states — at the time of the estimation — whether the reported cost was actually "observed" (i.e., cost actually incurred) or "potential" (i.e. not incurred but expected cost). *Method reliability* assesses the methodological approach used for cost estimation as of (*i*) "high" reliability if either provided by officially pre-assessed materials (peer-reviewed articles and official reports) or the estimation method was documented, repeatable and/or traceable if provided by other grey literature, or (*ii*) "low" reliability if not.

Synthesis of the cost estimates from the conservative subset

Biological invasions were estimated to cost a minimum of US$ 18.2 billion in Africa over the period 1970–2019 (Figure 3; Table 1). These conservative costs were not equally distributed across regions, between types of costs, or among sectors and taxa (Table 1).

Geographical regions

Recorded economic costs were spread unevenly across regions, with Southern Africa and Eastern Africa exhibiting the largest estimates (i.e. US$ 7.8 billion and US$ 6.8 billion, respectively). Apart from these two regions, Western Africa was the only region for which total costs exceeded US$ 1 billion (i.e. US$ 2.1 billion). The lowest reported costs included Middle and Northern Africa with US$ 267 million and US$ 196 million, respectively. Again, these cost estimates were mostly driven by a limited number of reporting countries (Suppl. material 5). When considering the reports of Southern Africa, Northern Africa and “diverse/unspecified” regions using the "conservative subset", the total costs were respectively four, twenty-five and thirty times lower compared with those obtained from the "starting dataset". This was mainly due to Southern Africa and ‘diverse/unspecified’ regions harboring a high proportion of potential costs, and Northern Africa reporting a substantial portion (almost 40%) of low-reliability cost estimates (Figure 2). Conversely, the total costs reported from the other regions decreased by less than 10% following the filtering steps, indicating that most of the costs reported in these areas were actually observed as well as of a high level of reliability.

Type of costs

The majority of cost estimates reported throughout the continent were associated with “damage” costs (US$ 12.4 billion) rather than “management” costs (US$ 4.9 billion) (Table 1). This pattern was consistent across regions and was even exacerbated for Eastern, Central and Western Africa where “damage” costs represented at least 99% of the recorded costs in each region (Figure 3; Suppl. material 5; see Suppl. material 9 for country-specific details). The single exception was Northern Africa for which the economic expenditures were exclusively associated with “management” costs. “Mixed” costs (US$ 846.6 million) were found exclusively and dominantly for “diverse/unspecified” regions, suggesting that costs with low spatial resolution may also have less precise and/or detailed information on the type of costs incurred by invaders.

Impacted sectors

Invasions had the greatest impacts on agriculture with, respectively, about 99% of the costs reported from Eastern and Middle Africa (Figure 3; Table 1). About 80% of the costs reported from Western Africa are also attributable to this economic sector (Figure 3; Table 1). Conversely, economic expenditures by authorities and stakeholders to manage invasions and/or to mitigate their impacts represents almost all costs incurred in Northern Africa and the greater proportion (about one third) of costs reported in Southern Africa (Figure 3; Table 1). Surprisingly, some sectors that we expected to be impacted were under-represented and/or spatially restricted. Indeed, environmental costs were only reported in Southern Africa and represent less than 15% of the total costs for this given region while marginal costs were found for fisheries (US$ 0.36 million from Western Africa), forestry (US$ 0.10 million from Southern Africa), social welfare (US$ 0.14 million from Eastern and Western Africa) and health (US$ 2.19 million from Eastern Africa) (Table 1). Moreover, we found that costs collated from “diverse/unspecified” regions were mostly related to a range of sectors concomitantly, rather than a specific single sector (i.e. about 90% of the total amounts; Figure 3). Overall, these regional patterns were also reflected at the national scale (Suppl. material 9).

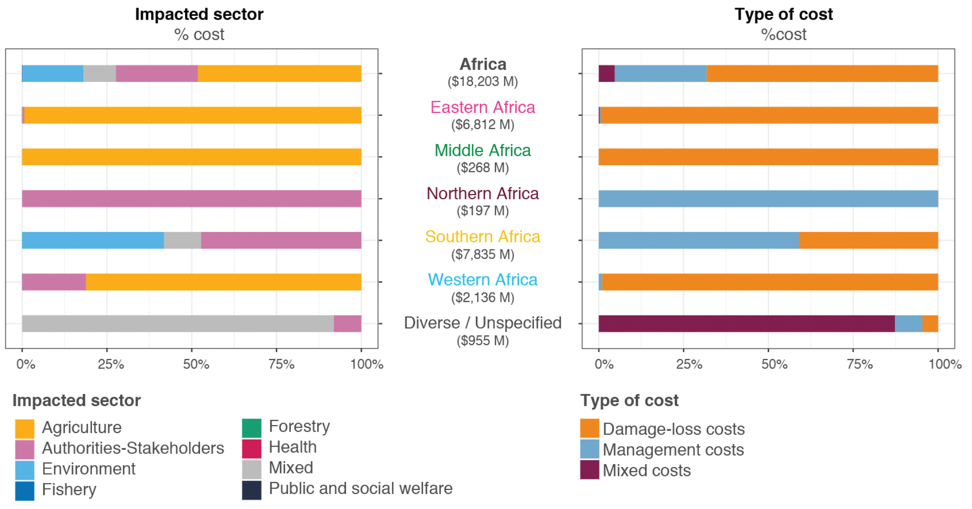

Figure 3. Distribution of reliable observed costs (using the *conservative subset*) following the impacted sectors and type of cost for each geographic region. For both impacted sectors and type of cost, we considered the definition and categories detailed in the Suppl. material 3 (see fields Impacted sectors and Type of cost merged).

Taxonomic groups

Cost estimates were reported for various animals (n = 16 species; US$ 7.9 billion) and plants (n = 45; US$ 8.6 billion), and one virus (US$ 1.6 billion) (Figure 4; Table 1; Suppl. material 10). Most of the recorded economic costs were driven by very few taxa, among which three of the five costliest species included insect pests: the spotted stem borer (*Chilo partellus*; US$ 2.6 billion), the fall armyworm (*Spodoptera frugiperda*; US$ 2,9 billion) and the tomato leafminer (*Tuta absoluta*; US$ 1,15 billion). The two other taxa contributing to the top five costliest species include the virus responsible for maize lethal necrosis (US$ 1.6 billion), attacking agricultural production in Eastern Africa (Pratt et al. 2017), and *Acacia* species (US$ 3.4 billion) which were introduced from Australia in the 19th century and now have strong environmental impacts (e.g. negative impacts on water availability) and management costs in Southern Africa (De Wit et al. 2001).

Temporal dynamics

The costs of biological invasions steadily increased over the period 1970–2019. During this period, invasions cost on average US$ 303 million per year and the mean cost exponentially increased over decades (Figure 5a). The mean cost in the current decade (US$ 919 million) is 310 times higher than those estimated in the 1980s (US$ 2.97 million). All models converged in their results and showed a high goodness-of-fit regarding the cost data (Figure 5b). Indeed, the variance explained by all models exceeds 85% with similar RMSE values; Suppl. material 11). Additionally, all modelling techniques confirmed that costs continuously increased each year since 1970 and there was

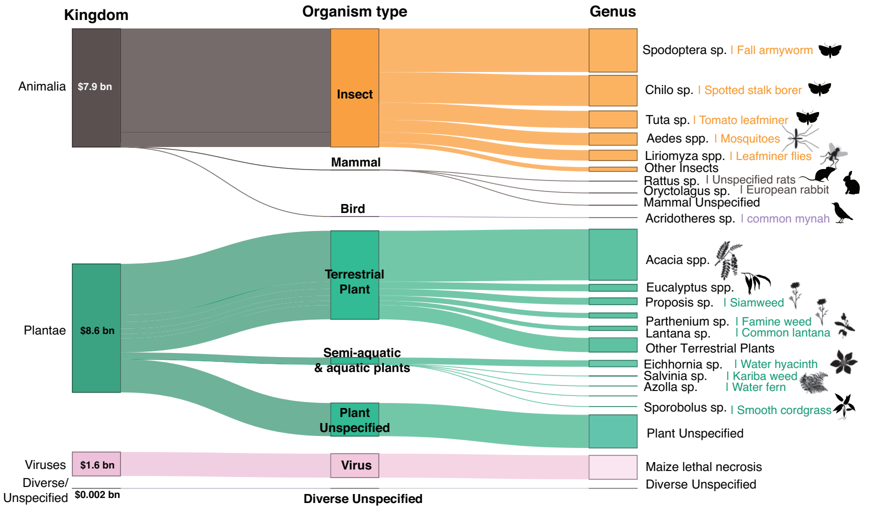

Figure 4. Distribution of the cost amounts (in 2017-equivalent US$ millions) among species recorded in the *conservative subset*. The species are successively grouped into kingdom, organism type and genus. The size of the bars (rectangles) is proportional to the cost value associated with either the kingdom, organism type or genus. For example, we can see that costs associated with the kingdom Animalia are equal to US$11.6 billion. Animalia comprises the organism groups insect, mammal and bird, so the combined height of the rectangles representing costs for insect, mammal and bird is equal to the height of the bar representing the Animalia Kingdom. Insects contribute the most to costs associated with Animalia and amongst insects, the genus Spodoptera sp. is the most costly. Icons are from (http://phylopic.org/).

no sign of abatement of cost amounts in the most recent years. We found an 8-fold increase in the mean cost each decade. Therefore, we estimated that the average annual cost of invasions in 2019 could range between US$ 2.6 billion (predicted by the GAM) and US$ 8.6 billion (predicted by the linear robust regression).

Discussion

Massive economic toll

Our findings undoubtedly illustrate that invasions incur substantial costs to national African economies, most of them being vulnerable and already weak (Lekunze 2020). The reported financial burden accumulated to a conservative total of approximately US$ 18.9 billion (annual average of US$ 303 million) between 1970 and 2019, reaching an estimated annual average of US$ 2.6–8.6 billion in 2019. However, these costs could seem relatively low compared with those from other continents such as North America (Crystal-Ornelas et al., submitted in the current issue), Europe (Haubrock et al., submitted in the current issue) or Asia (Liu et al., submitted in the current issue). On the one hand, this discrepancy likely reflects the strong geographical imbalance in research intensity and financial capacities (Early et al. 2016; Sooryamoorthy 2018)

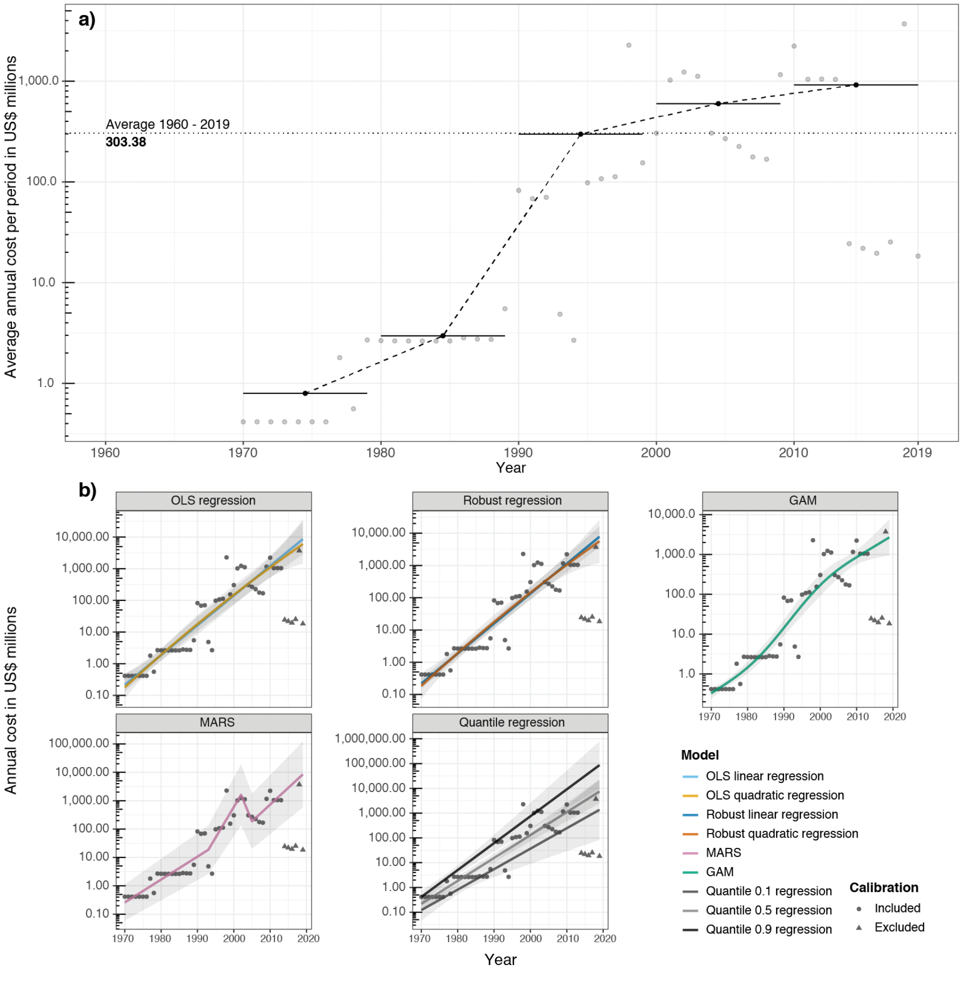

Figure 5. Temporal trends (1970–2019) of costs (in 2017-equivalent US$ millions) **a** considering the actual distribution of the mean amounts provided for each decade in the *conservative subset* and **b** using model predictions (i.e. OLS: ordinary least-squares; GAM: generalized additive model; linear regression, quadratic regression, MARS: multiple adaptive regression splines) and quantile regressions. We considered models calibrated and fitted with at least 75% of cost data completeness from the dataset. We $\log_{10}$-tranformed cost estimates using information from the *cost estimate per year 2017 USD exchange rate* column in the *conservative subset*).

rather than the actual spatial distribution of the costs of invasions. Also, invasion-associated issues may not be perceived as a priority for many African countries where investments in many primary structural needs (e.g. roads, infrastructures, fight against extreme poverty, and building sustainable education and health systems) are still greatly needed (African Development Bank Group 2018; Adamjy et al. 2020). This may logically translate into reduced academic studies and operational programs on biological invasions. Accordingly, IAS were dramatically understudied in Africa compared with other parts of the world (Pysek et al. 2008) – with a notable exception being South Africa (van Wilgen et al. 2020). Moreover, wealthier or developed regions are also those with higher documented invasions and associated impacts (Bellard et al. 2016; Essl et al. 2020). In addition, the significant difference in both values of the money and price levels between areas (e.g. labor costs for similar management actions are likely cheaper in most African countries when compared with those in Europe or North America), might be contributing to increment the observed discrepancy in reported costs between Africa and other regions. Indeed, relevant monetary comparisons at macroeconomic scale require reliance on indicators such as the purchasing power parity (but see Gosh 2018), which reflects the relative purchasing power of different currencies between countries and over time. However, such reliable comparisons are still prevented by very limited information on this indicator for most countries and/or years (Diagne et al. 2020b). We therefore have to also acknowledge that some African countries invest a substantial amount of resources towards the appropriate management of invaders – as evidenced by the increasing successful control of invasive alien plants in several African countries such as South Africa and Namibia (Stafford et al. 2017). The cost estimates presented here are substantial and obviously detrimental for the African continent. An eloquent illustration comes from comparing our estimated costs with the African Union's budget (https://au.int/). In 2019, the expected minimum cost of invasions was more than three times higher than the entire budget available for this continental organization (i.e. US$ 681.5 million in 2019). Therefore, we can safely assume that our conservative estimate of invasion costs largely exceeds the actual funding capacities of the largest regional organizations that support socio-economic development in African countries. Moreover, the highest average value estimated for 2019 (US$ 8.6 billion) is greater than the individual gross domestic products of the seventeen less developed countries across the whole continent.

Increasing costs over time

Worryingly, we found that the economic costs of IAS in Africa are steadily increasing over time without any signs of slowing down, reflecting the continuous increase in the number of IAS worldwide (Seebens et al. 2017). A set of complementary reasons may explain this temporal pattern, and/or why we should not expect any deceleration in invasion costs in the years to come. First, there is a growing awareness of the impacts of invaders as well as a burgeoning interest in reporting their economic impacts along with an associated increase in management actions during recent years (Dana et al. 2013; Simberloff et al. 2013; Diagne et al. 2021). Scrutinizing our dataset reveals that while the first monetized impacts of IAS in Africa dates back to the 1970s, the first document providing IAS costs was published in 1991 (Suppl. material 4). All cost estimates recorded between 1970 and 1985 stemmed from only three sources which reported costs for South Africa and Indian Ocean islands, suggesting that the research interest in other African regions has been growing rapidly over the past few decades. Second, the ongoing globalization and climate change synergistically accelerate the opportunities and rate of species invasions almost everywhere, and Africa should be no exception (Seebens et al. 2015; Faulkner et al. 2020). Third, Africa has been shown to be among the key areas at risk for future invasions by at least 86 of 100 of the world's worst invasive species, with most of these invasions likely to cause severe socio-economic impacts (Faulkner et al. 2020). The role of the socio-economic changes faced by most African areas is undebatable in this particular context. In particular, Africa is currently experiencing a rapid rate of urbanization that is only second to Asia, with an urban population that may at least triple between 2010 and 2050 to reach 1.339 billion people (Matamanda and Nel 2020). Evolutionary socio-ecological features associated with this urbanization process can promote invasion success (Klotz and Kühn 2010; Sinka et al. 2020). For example, the dense and various networks of exchanges of goods and people can create repeated opportunities for the introduction of a wide range of exotic species and a shift towards biotic and abiotic conditions can greatly favor opportunistic, adaptable and prolific species. In that sense, empirical evidence supporting this process was recently provided for different invasive taxa, including rodents in Western African countries (Garba et al. 2014; Hima et al. 2019) and cultivated ornamental plants in South Africa (Potgieter et al. 2020). Unfortunately, these examples constitute only a few among several others which demonstrates the changing context-related spread of harmful invaders throughout the continent (Early et al. 2016). The increasing costs reported here sound alarming, yet there are several reasons which can explain why these costs are likely much higher than we estimated.

Underestimated economic burden

A number of logistical, methodological and cost-intrinsic factors may have prevented the capture of the complete diversity – and thus the full amount – of costs. Costs can remain hidden and/or underestimated due to (*i*) the unclear status of some invasive species (Jarić et al. 2019), (*ii*) inaccessible source materials (e.g. grey literature; Adams et al. 2017), and (*iii*) methodological (e.g. inadequate extrapolations; see Jackson (2015) for a detailed synthesis) as well as ethical issues (e.g. monetary perception of ecosystem services; Meinard et al. 2016) that impair the evaluation process (Bradshaw et al. 2016; Hoffmann and Broadhurst 2016). For instance, costs from well-known economically harmful invaders could have been overlooked simply because they failed to be captured when building the "InvaCost" database (Diagne et al. 2020b, 2021). Moreover, costs are inherently complex and heterogeneous. As a consequence, misconceptions from the lack of reporting consistency in invasion science (Colautti and MacIsaac 2004; Richardson et al. 2020) likely lead to overlooking some cost estimates (Dana et al. 2013). Furthermore, we made highly conservative choices when generating our "conservative subset" in order to ensure reliable cost assessments, which led to consider only 2,302 out of 4,259 cost entries from the "starting dataset" (e.g. for some countries, such as Morocco and Angola, all costs were unreliable or potential, and were therefore discarded following our filtering procedure). More broadly, the skewed cost distribution (see below) revealed taxonomic, sectoral and geographic gaps that may contribute to our underestimations of the actual economic burden of IAS in Africa.

Geographic imbalance in the reported costs

We showed that economic costs are widely but not evenly distributed across regions. Indeed, most cost estimates were associated with a single country (i.e. South Africa), which is internationally recognized as a pioneering and frontline country for research and management in invasion science (van Wilgen et al. 2020). It has been shown that South Africa comprised about two-thirds of the quantified research effort in the field across the African continent (Pysek et al. 2008). A similar unevenness has been found in relation to aquatic invasion costs, where South Africa dominated costs reported on the African continent (Cuthbert et al. 2021). The rich history of species introductions, higher economic capacity (compared with most African countries) and long tradition of large-scale conservation actions in this country may also contribute to this trend (Foxcroft et al. 2020; van Wilgen et al. 2020). Another reason for the higher cost estimates for South Africa comes from the fact that South African studies often rely on extrapolation-based approaches to provide economic estimates of IAS impacts (van Wilgen et al. 2020). Yet, these potential cost data were filtered out of our "conservative subset", explaining why the total cost for Southern Africa significantly decreased after filtering to reach an amount comparable to costs from Eastern Africa (Table 1). The high costs reported for Eastern Africa may be – at least partially – linked to the research activity of the Centre for Agricultural Bioscience International (CABI; www.cabi.org) and work done by the United Nations Environmental Program (UNEP) which have their regional centers located in Nairobi (Kenya).

Moreover, we may expect higher costs for the other regions than those reported here. For instance, Northern Africa has 13 cost entries recorded for only five species, while 157 species are listed in the GISD for this region. Also, Western African countries are historically and contemporarily threatened by a broad variety of biological invaders which is beyond insects and plants that were mostly reported for this region. Indeed, the succession of large international seaports along coastal cities (e.g. Abidjan, Cotonou, Lagos, Dakar) and the parallel development of the extensively urbanizing corridor from Côte d'Ivoire to Nigeria (i.e. the so-called Abidjan-Lagos corridor) may greatly facilitate the introduction of several vertebrate and aquatic invertebrate invaders (Habitat 2014; Bellard et al. 2016; Hima et al. 2019). Consequently, we advocate for increasing research effort towards the economic costs of biological invasions, mainly in the understudied regions where the costs are likely to be much higher than those currently reported.

Biased costs towards agriculture

Across the African continent, most of the reported costs were mainly driven by very few taxa, among which the costliest included three insect pests: the spotted stem borer (*C. partellus*), introduced in Eastern Africa in the 1930s, is suspected to be the most serious pest of maize and sorghum in Eastern and Southern Africa (Yonow et al. 2017); the fall armyworm (*S. frugiperda*) has now been reported in 45 African countries since its first report in Western Africa in late 2016, and is a known voracious consumer of more than 80 crop species of strong nutritional and socio-economic utility (CABI 2020); the tomato leafminer (*T. absoluta*) has now invaded 41 of the 54 African countries since its introduction in Northern Africa in 2007 (Rwomushana et al. 2019). Given the broad distribution (beyond the limited spatial coverage of each of these species in the database) and biological characteristics of these invasive pests, we can safely assume that their economic impacts largely exceed the monetary costs reported here (see Eschen et al. 2021 for a recent extrapolation attempt, using information obtained from the literature and stakeholder consultations). In this study, *T. absoluta* and *S. frugiperda* were still among the five costliest IAS, together with the invasive plants *Eichhornia crassipes*, *Lantana camara* and *Prosopis juliflora*. Typically, the over-representation of agriculture in the reported costs may reflect the direct influence of economic priorities and societal realities in political and research agendas. Indeed, building sustainable agriculture for food security is a priority for most African countries and their economies sometimes strongly rely on food production (Pratt et al. 2017; Wiggins et al. 2010). Given that Africa is highly vulnerable to invasions by exotic pests (Early et al. 2016; Paini et al. 2016), it would seem logical that local authorities invest more on research in the agricultural sector, especially given the very limited economic resources of these countries to fight against invaders (Early et al. 2016; Faulkner et al. 2020).

Focusing solely on major and well documented (and often mediatized) agricultural threats may have an 'umbrella' effect on other less visible but harmful invaders for which the costs may be unsuspected or neglected. Indeed, only a small spectrum of species (about 15%) from those recognized as invading Africa in the GISD were reported here. This strongly corroborates a previous assumption that only a small portion of invaders have been economically analyzed (Aukema et al. 2011). Besides, many of the species recorded in our dataset can have a broader range of economic impacts. An eloquent example of this is provided by rodent species (e.g. *Rattus* spp. and *Mus musculus*) for which only management costs were reported here. Yet, invasive rodents are responsible for significant damage costs to humans (e.g. medical care due to zoonotic infections, losses from consumption of stored food stocks, destruction of infrastructures and electric supply networks) (Drummond 2001; Han et al. 2015), as recently illustrated in different parts of Africa (Leirs et al. 2010; Dossou et al. 2020).

Therefore, it is evident that research intensity is closely connected with societal and economic realities in African countries. Hence, strong collaborations should be established and/or amplified between scientists, authorities, various sectoral stakeholders as well as local communities to understand and deal with the multidimensional issues raised by biological invasions.

Call for integrated and concerted management efforts

Our results clearly highlight that IAS are a significant economic burden in Africa and the costs of these invasions are largely driven by damage induced by invaders. Monetary estimates associated with managing invasions were scarce and the amounts spent were essentially restricted to South Africa and North Africa. This pattern reflects a missed opportunity, since one of the rare examples we have for the entire African continent (i.e. the biological control of the cassava mealybug) suggests a benefit-cost ratio of management of 200 at minimum (Zeddies et al. 2001). If the lower investment in management is real (and not only under-reported), we hypothesize that this lower investment in management could possibly reflect a lack of awareness and/or insufficient capacities and means from national authorities and decision-makers facing invasions. Yet, invaders represent a significant shortfall for low income countries. In addition, this enormous financial toll represents only part of all the impacts incurred from invasions, which are also associated with major ecological and health issues (Kumschick et al. 2014; Ogden et al. 2019). Our findings should therefore be interpreted as an urgent call for considering invasion management as a major piece of sustainable development in these developing countries (Larson et al. 2011; Shackleton et al. 2017), in parallel with many of the Sustainable Development Goals defined by the United Nations and which serve as political, socio-economic and ethical guidelines globally (Sach et al. 2019).

We argue that efficient strategies towards management require cross-disciplinary and cross-sectoral efforts within and between scientists, decision-makers, stakeholders and civil society (Courchamp et al. 2017; Vaz et al. 2017; Richardson et al. 2020). Indeed, if research is necessary to produce knowledge about origin, impacts and spread of invasive species, a supportive political environment is critical to develop and implement long-term policies in Africa (Evans et al. 2018; Adamjy et al. 2020). Moreover, it has been shown that insufficient appreciation of socio-political context, non-existent or perfunctory public and community engagement, as well as unidirectional communications were associated with conflictual invasive species management (Crowley et al. 2017). Since an invasive species can be viewed as detrimental, neutral, or even beneficial in society, people who benefit from IAS may differ from those who suffer the costs (Estévez et al. 2015; Novoa et al. 2016b; Adamjy et al. 2020). As such, applying principles and concepts of sustainability science to invasion research and management should represent a key opportunity within the African context (Gasparatos et al. 2017; Tortell 2020). In addition, scientists and stakeholders need to engage in a joint paradigm for the concerted implementation of context-adapted policies and concerted implementation of management measures at relevant scales (Novoa et al. 2018).

The adoption and implementation of biosecurity measures appear particularly relevant for African countries where economic capacities are often limited. This is particularly true since many invaders introduced from other continents are also spreading within Africa in unpredictable directions (Faulkner et al. 2017; Keller and Kumschick 2017). The ultimate objective should be to act against invaders before they are introduced or become widely established, since controlling widespread invasions is often impossible or may require a high amount of resources. Furthermore, these actions should be applied at regional scales to balance expenditures and improve efficiency of actions (Faulkner et al. 2020). To date, such examples of regional cooperation are still scarce across the continent and the few attempts are restricted to South Africa (e.g. Shackleton et al. 2017). Our findings stress the need for integrating and/or reinforcing the place of biological invasions in the official agendas of African regional organizations.

Conclusion

Our study provides the first comprehensive overview of the reported economic costs of biological invasions in Africa over the last fifty years. We showed that invasions represent a massive, yet highly underestimated economic burden for African countries, and their reported costs are exponentially increasing over time. We also highlighted crucial, large gaps in the current knowledge on invasion costs that still need to be bridged with more active and widespread research and management across the continent. The cost figures presented in this paper should be seen as a snapshot of the cost information currently available in the updatable "InvaCost" database, rather than definitive cost values (and temporal/spatial distribution of costs). We consider this work a sound basis for improving further research on this topic and envision future updates for this first state-of-the-art synthesis of the economic costs of invasions in Africa. Finally, our study provides support for developing and implementing biosecurity measures as well as integrated post-invasion management actions at both national and regional levels. Taking into account the complex societal and economic realities of African countries, the currently neglected problem of invasions should be dealt with using holistic and sustainable approaches. Indeed, beyond their economic impacts, invasions also have substantial impacts on biodiversity, human health and food security. Therefore, we advocate for (*i*) an increase in societal awareness on biological invasions through improved science-society interactions on this topic and (*ii*) the systematic inclusion of invasion costs in the development of regulations and actions targeting invasive species in Africa.

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Supplementary material 1

Starting dataset considered in this study

Authors: Christophe Diagne, Anna J. Turbelin, Desika Moodley, Ana Novoa, Boris Leroy, Elena Angulo, Tasnime Adamjy, Cheikh A. K. M. Dia, Ahmed Taheri, Justice Tambo, Gauthier Dobigny, Franck Courchamp

Data type: database

Explanation note: This database results from the combination of data collated in the "InvaCost" database (Diagne et al. 2020b) and two other complementary databases available at https://doi.org/10.6084/m9.figshare.12928145.v1 and https://doi.org/10.6084/m9.figshare.12928136. The first spreadsheet (called "Basic data") contains the complete database focusing on cost data exclusively associated with the African continent. The second spreadsheet (called "Expanded data") contains the expanded version of the complete database.

Link: https://doi.org/10.3897/neobiota.67.59132.suppl1

Supplementary material 2

Data collection and filtering processes

Authors: Christophe Diagne, Anna J. Turbelin, Desika Moodley, Ana Novoa, Boris Leroy, Elena Angulo, Tasnime Adamjy, Cheikh A. K. M. Dia, Ahmed Taheri, Justice Tambo, Gauthier Dobigny, Franck Courchamp

Data type: database

Explanation note: (a) Collection of cost information from the version 3.0 of "InvaCost"; (b) extraction of relevant data using the "Geographic region" and "Country" fields to obtain the "starting dataset"; (c) homogenization of cost entries to cost estimates per year expanded over time and (d) selection of the most "conservative subset" using the "Implementation" and "Reliability" variables.

Link: https://doi.org/10.3897/neobiota.67.59132.suppl2

Supplementary material 3

Summary of the descriptive columns of the database used in this study (from Diagne et al. 2020c)

Authors: Christophe Diagne, Anna J. Turbelin, Desika Moodley, Ana Novoa, Boris Leroy, Elena Angulo, Tasnime Adamjy, Cheikh A. K. M. Dia, Ahmed Taheri, Justice Tambo, Gauthier Dobigny, Franck Courchamp

Data type: database

Explanation note: The different columns (i.e. descriptive variables) are italicized and presented in alphabetical order. The categories used for each descriptive variable are put in bold. All fields actually considered in our study are marked with an asterisk.

Link: https://doi.org/10.3897/neobiota.67.59132.suppl3

Supplementary material 4

Conservative subset obtained following specific filtering steps applied to the starting dataset

Authors: Christophe Diagne, Anna J. Turbelin, Desika Moodley, Ana Novoa, Boris Leroy, Elena Angulo, Tasnime Adamjy, Cheikh A. K. M. Dia, Ahmed Taheri, Justice Tambo, Gauthier Dobigny, Franck Courchamp

Data type: database

Explanation note: This dataset only contains estimates that are considered as actually realized and perceived as of high reliability (based on the type of publication and method of estimation). The first spreadsheet (called "Basic data") contains the complete subset focusing on cost data exclusively associated with the African continent. The second spreadsheet (called "Expanded data") contains the expanded version of the complete subset.

Link: https://doi.org/10.3897/neobiota.67.59132.suppl4

Supplementary material 5

Quantitative summary of the cost data and estimates

Authors: Christophe Diagne, Anna J. Turbelin, Desika Moodley, Ana Novoa, Boris Leroy, Elena Angulo, Tasnime Adamjy, Cheikh A. K. M. Dia, Ahmed Taheri, Justice Tambo, Gauthier Dobigny, Franck Courchamp

Data type: database

Explanation note: Quantitative summary of the cost data and estimates for each African country recorded in the "starting dataset" and the "conservative subset" according to their perceived level of reliability (“high” versus “low”) and implementation (“observed” versus “potential”). We used the expanded version of both datasets to provide the total cumulative costs (between 1970 and 2020) in 2017-equivalent US$ billion. *N* represents the number of cost entries in the datasets. Details about the descriptive fields and their respective categories are provided in the Suppl. material 3.

Link: https://doi.org/10.3897/neobiota.67.59132.suppl5

Supplementary material 6

Categorization of recorded cost data into “damage” costs

Authors: Christophe Diagne, Anna J. Turbelin, Desika Moodley, Ana Novoa, Boris Leroy, Elena Angulo, Tasnime Adamjy, Cheikh A. K. M. Dia, Ahmed Taheri, Justice Tambo, Gauthier Dobigny, Franck Courchamp

Data type: database

Explanation note: Categorization of recorded cost data into “damage”, “management” or “mixed” costs according to criteria considered in Diagne et al. 2020c (see also Suppl. material 3).

Link: https://doi.org/10.3897/neobiota.67.59132.suppl6

Supplementary material 7

Relative weights of predictor categories in the linear robust regression between cost data and time period

Authors: Christophe Diagne, Anna J. Turbelin, Desika Moodley, Ana Novoa, Boris Leroy, Elena Angulo, Tasnime Adamjy, Cheikh A. K. M. Dia, Ahmed Taheri, Justice Tambo, Gauthier Dobigny, Franck Courchamp

Data type: database

Explanation note: 'Cost data' is the response variable: we considered information from the Cost estimate per year USD Exchange rate column in the expanded conservative subset (Suppl. material 4). 'Time period' (in years) is the predictive variable: we considered information from the Impact year column of the expanded subset conservative subset (Suppl. material 4). We identified that the relative weights of all years from 2014 onwards (except 2018) are lower than those from previous years. These years (including 2018) were therefore removed when calibrating the final models investigating the trend of cost over time.

Link: https://doi.org/10.3897/neobiota.67.59132.suppl7

Supplementary material 8

Quantitative summary of the costs reported in each African region

Authors: Christophe Diagne, Anna J. Turbelin, Desika Moodley, Ana Novoa, Boris Leroy, Elena Angulo, Tasnime Adamjy, Cheikh A. K. M. Dia, Ahmed Taheri, Justice Tambo, Gauthier Dobigny, Franck Courchamp

Data type: database

Explanation note: Quantitative summary of the costs reported in each African region following the number of expanded cost entries (*N*), the "method reliability" ("High" or "Low") and the cost "implementation" ("observed" or "potential").

Link: https://doi.org/10.3897/neobiota.67.59132.suppl8

Supplementary material 9

Distribution of the reliable observed costs

Authors: Christophe Diagne, Anna J. Turbelin, Desika Moodley, Ana Novoa, Boris Leroy, Elena Angulo, Tasnime Adamjy, Cheikh A. K. M. Dia, Ahmed Taheri, Justice Tambo, Gauthier Dobigny, Franck Courchamp

Data type: database

Explanation note: Distribution of the reliable observed costs (from the conservative subset) following the impacted sectors and type of cost for each reporting African country. The country names are coloured based on the geographical region they belong to as defined by United Nations geoscheme (available at https://unstats.un.org/): "Western Africa", "Southern Africa", "Northern Africa", "Middle Africa", and "Eastern Africa" (see continental map on the top left corner). For the impacted sectors, we considered the categories proposed by Diagne et al. (2020b) (Suppl. material 3). For the type of cost, we used the information from the type of cost column to classify the cost estimates among "damage" costs (economic losses due to direct and/or indirect impacts of invaders, such as yield loss, health injury, land alteration, infrastructure damage, or income reduction), "management" costs (economic resources allocated to actions to avoid the invasion, or to deal with more or less established invaders such as prevention, control, research, long-term management, eradication) or "mixed" costs (when costs include both damage and management expenditures) (Suppl. material 6).

Link: https://doi.org/10.3897/neobiota.67.59132.suppl9

Supplementary material 10

List of species as well as their cost estimates recorded in our dataset

Authors: Christophe Diagne, Anna J. Turbelin, Desika Moodley, Ana Novoa, Boris Leroy, Elena Angulo, Tasnime Adamjy, Cheikh A. K. M. Dia, Ahmed Taheri, Justice Tambo, Gauthier Dobigny, Franck Courchamp

Data type: database

Explanation note: We provided the total cumulative costs in 2017-equivalent US$ million for 1970-2020 derived from the "starting dataset" (i.e. total cost) and "conservative subset" (i.e. robust cost).

Link: https://doi.org/10.3897/neobiota.67.59132.suppl10

Supplementary material 11

Summary of the outputs from the different models used for analyzing the temporal trend of invasion costs in Africa between 1970 and 2019

Authors: Christophe Diagne, Anna J. Turbelin, Desika Moodley, Ana Novoa, Boris Leroy, Elena Angulo, Tasnime Adamjy, Cheikh A. K. M. Dia, Ahmed Taheri, Justice Tambo, Gauthier Dobigny, Franck Courchamp

Data type: database

Explanation note: Prediction was based on OLS: ordinary least-squares; GAM: generalized additive model; linear regression, quadratic regression, MARS: multiple adaptive regression splines. We considered models calibrated and fitted with at least 75% of cost data completeness from the dataset. Costs are estimated in 2017-equivalent US$ millions. We $\log_{10}$-tranformed cost estimates (from the 'Cost estimate per year 2017 USD exchange rate' column in the InvaCost database).

Link: https://doi.org/10.3897/neobiota.67.59132.suppl11