Biol Invasions (2024) 26:4317–4330
https://doi.org/10.1007/s10530-024-03448-6

ORIGINAL PAPER

Networks of risk: international tourists as a biosecurity pathway into national parks

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Received: 23 May 2024 / Accepted: 13 September 2024 / Published online: 20 September 2024

Abstract International tourists are recognised as vectors of alien microbes, plants, and animals into protected areas worldwide, either by introducing species from overseas or redistributing alien species within a region. Quantitative estimates of the risk from this introduction pathway have relied on surveys of invasive alien species associated with tourist clothing or transport vectors. In contrast, the large-scale movement of tourists across multiple protected areas within a region has rarely been examined. The New Zealand International Visitor Survey was used to estimate the frequency with which several thousand international travellers visited the nation's 13 national parks. Trends in international visitor movements were compared immediately prior to the closure of international borders due to the SARS-CoV-2 pandemic and again once the border had reopened. Approximately one-third of international visitors only visited a single national park but over 20% visited five or more. The long tail in the frequency of national parks visited highlights that a small number of tourists pose a greater risk of introducing or moving invasive alien species among different protected areas. European tourists visited more national parks and were more likely to camp or stay in mountain huts while in New Zealand, potentially posing a greater biosecurity risk than other nationalities. The largely montane nature of most national parks imposes a strong bioclimatic filter on alien species establishment and combined with border controls, suggests international tourists pose a greater risk by disseminating already established alien species more widely among and within national parks. Network analyses highlighted geographic clustering of national parks based on tourist movements that might facilitate regional spread of alien species. Greater investment in the education of international tourists about the biosecurity risks they pose through spreading alien species into national parks is needed to address Target 6 of the Global Biodiversity Framework.

Keywords Behaviour change · Biological invasions · Climate change · Dispersal · Mountains · Surveillance · Tourism · Weeds

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Introduction

The Kunming-Montreal Global Biodiversity Framework sets forth an ambitious global biodiversity agenda committing Parties to the Convention for Biological Diversity (CBD) to meet 23 action-oriented global targets for urgent action over the decade to 2030 (Convention on Biological Diversity 2022). In particular, Target 6 requires Parties to the CBD to identify and manage pathways of the introduction

of alien species with an overall goal to reduce the rates of introduction and establishment of invasive alien species by at least 50% by the end of the decade (Hughes and Grumbine 2023). Approaches to manage the introduction pathways of alien species have been well understood for over a decade (Hulme et al. 2008) and today standardised data are available documenting the pathways of introduction of a wide range of alien organisms for many regions of the world (McGrannachan et al. 2021; Saul et al. 2017). Yet, despite this increased understanding of introduction pathways, the Aichi Biodiversity Target to manage introduction pathways of invasive alien species by 2020 was not met (Nature 2020). Assessment of the current Kunming-Montreal Biodiversity Framework suggests that Target 6 also is unlikely to be met by 2030 (Hughes and Grumbine 2023). Therefore the current approach to pathway management needs to be more nuanced and directly address the specific pathways that lead to the spread of species within a particular region.

To date, many of the concerns regarding introduction pathways have focused on the role of international trade (Hulme 2021; Montgomery et al. 2023), but despite its potential importance in the global spread of alien species (Hulme 2015), the role of international tourism as a direct or indirect pathway of alien species introduction has received less attention (Anderson et al. 2015; Barros et al. 2022). International tourists introduce alien species inadvertently to new regions in their luggage (Liebhold et al. 2006), clothing (Chown et al. 2012), and on the soles of their footwear (Ware et al. 2012). They have also been implicated in the introduction of human ectoparasites (Reinhardt and Siva-Jothy 2007) as well as the global spread of several human pathogens (Sacramento 2023). While each individual tourist may pose a small risk, the sheer volume of tourists travelling around the world results in a potentially high, but poorly quantified, propagule pressure (Hulme 2015).

While the concerns regarding the international tourist pathway have largely focused on preventing alien species introductions across national borders (Hall 2019; Melly and Hanrahan 2023; Robinson and McNeill 2022), international tourists are highly mobile within the countries they visit and are also likely to redistribute established alien species to new areas within the same region. International tourists have been implicated in moving seeds of environmental weeds, molluscs, and plant pathogens via clothing, equipment (such as backpacks), and footwear into protected areas (Pickering and Mount 2010; Sun and Walsh 1998). Yet the relative role of international tourists as significant pathways for post-border spread of alien species is poorly understood. Understanding the within-country movements of international tourists would be an important component of any assessment that aims to quantify the risk they may pose as vectors of invasive alien species.

To assess this risk from a conservation perspective, it is essential to know where international tourists travel to after they have entered a country and their propensity to visit locations of high biodiversity value (such as national parks). If international tourists visit multiple national parks during their vacation, then the risk of spreading alien species into these sites is increased. Furthermore, knowledge of the likelihood that they go for walks or stay overnight at camp sites in protected areas would provide an indication of the risk of spreading alien species. Walking trails are recognised as important conduits for the spread of alien plants into protected areas both by creating disturbed ground but also facilitating the transport of seeds on footwear (Liedtke et al. 2020). Similarly, camp sites are a major route through which alien plants and pathogens can become established in protected areas (Pickering and Hill 2007) Campsites can act as hotspots for the inadvertent introduction of alien species, especially plants whose seeds can being attached to tent floors, car mats, shoes and clothing, and car tires (Kangas et al. 2007; Tobin et al. 2010; Verloove et al. 2020).

As an isolated archipelago with high levels of endemism, New Zealand is particularly vulnerable to the threat of biological invasions (Lester 2022). Yet at the same time, the New Zealand economy is strongly dependent on international tourism with this sector contributing over 5% of GDP and 8% of total employment in 2020 (Organization for Economic Cooperation and Development 2022). Since 2018, New Zealand has experienced over-tourism with noticeable impacts on the natural environment which is only likely to become intensified in the future as the total number of international tourists visiting each year begins to exceed the entire domestic population (Insch 2020).

New Zealand also has a strong domestic tourism industry, but the evidence suggests that international

tourists pose a greater overall biosecurity risk to New Zealand national parks (Parliamentary Commissioner for the Environment 2019). At the border Chinese visitors represent a four times higher risk of being found with undeclared items, while Indian visitors are at almost six times higher risk than comparable New Zealand residents (Sheridan 1989). Compared to overseas visitors, domestic tourists tend to be more regionally focused, often centred on urban areas, undertake day trips to less visited protected areas, with national parks visited more frequently in winter for skiing (Ganglmair-Wooliscroft and Wooliscroft 2014; Lück 2008; Pearce and Booth 1987; Shultis 1989). For example, New Zealand's Great Walks are premier multiday walking trails that pass through diverse and spectacular scenery within several national parks but the majority of users are international tourists (Fagan and Kearns 2017).

International tourists generally tour the entire country with national parks playing a prominent role as nodes in the international tourist circuit with the result that international visitors dominate during summer months with over one-third staying overnight in national parks (Lück 2008; Pearce 1999; Pearce and Booth 1987; Shultis 1989). However, these travel patterns are often dependent on the nationalities of tourists and differences exist in terms of length of stay, motivations, interests, travel style and travel experience. For example, Germans are more likely to be free independent travellers and to visit remote locations over an average period of six weeks, whereas Japanese and Chinese visitors tend to concentrate around urban centres as part of organised tours that last less than a fortnight (Becken et al. 2008).

A further difference between domestic and international visitors to national parks relates to their awareness of biological invasions. New Zealand residents have a greater awareness of alien plant species, are less accepting of these species, and are more supportive of their eradication than international tourists (Lovelock et al. 2023). An additional concern is that international visitors may be more accepting of invasions by attractive, showy alien plants (Lovelock et al. 2022) which is a considerable issue give that most invasive alien weeds in natural areas stem originally from ornamental plantings (Hulme 2020). There is also evidence that international visitors are less well informed than New Zealand residents regarding the impacts introduced plant diseases have on endemic species and usually they are less likely to use footwear cleaning stations when these are available (Ovenden 2020).

What evidence exists to suggest international tourists pose a significant biosecurity risk? Surveys of international tourists entering New Zealand have previously found that a single gram of soil attached to footwear can harbour: 5×10^6 bacteria, 5×10^4 fungi, 3 seeds, 40 nematodes and 0·004 mites and these taxa may often include potential invasive alien species (McNeill et al. 2011). Clothing and luggage of incoming passengers into New Zealand have also been shown to host fungal spores (Sheridan 1989). Risks may be higher from individuals who plan to camp and/or hike in national parks since used tents brought into New Zealand have been found to harbour not only plant debris but also live invertebrates (Gadgil and Flint 1983). Despite investment in the use of detector dogs and X-ray screening of luggage on arrival, such interventions can never be completely effective and at least 3% of risk items slip through the border (Ministry for Primary Industries 2013). With almost 4 million international tourists arriving each year in New Zealand prior to the SARS-CoV-2 pandemic (Organization for Economic Cooperation and Development 2022) even a 3% slippage rate represents over 100,000 risk items entering the country annually. There are frequent reports in the media of organisms ranging from insects to reptiles slipping through the border in tourist luggage (Mackay et al. 2024). Supporting this view of international tourists being a potential source of biosecurity risk in New Zealand is the finding that records of alien species incursions have been related to the number of tourist guest nights spent in a locality (Robinson and McNeill 2022).

Once through the border, international tourists can travel several thousand kilometres during the relatively short periods they spend on vacation in New Zealand (Becken and Schiff 2011) and thus the potential to introduce and or spread alien species widely appears high. The strongest evidence for the role of visitors to national parks being vectors for the introduction of alien species stems from the observation of alien plant species associated with walking trails (Jesson et al. 2000) or huts (Lloyd et al. 2006), especially in remote locations (Johnson 1982). International tourists have been implicated in the initial introduction of the alien

diatom *Didymosphenia geminata* into waterbodies in New Zealand (Kilroy and Unwin 2011) and its subsequent spread by visitors into the following South Island national parks: Mt Aspiring (2006), Fiordland (2007), Kahurangi (2008), and Nelson Lakes (2011). Bedbugs (*Cimex lectularius*) have experienced a global resurgence and these insects are strongly linked to increased international budget travel and often associated with low-budget accommodation, in particularly the backpacker-style hostels (Liu and Pennington-Gray 2015). International visitors are alleged to have been the source of outbreaks of bedbugs at popular Department of Conservation (DOC) huts in Rakiura and Fiordland National Parks in New Zealand over the last decade. It is therefore essential to understand the role international tourists play in introducing alien species into sensitive environments, such as protected areas both in terms of new introductions as well as the spread of established alien species.

To address this issue, the movement data of several thousand international visitors to New Zealand was interrogated to examine the spatial and temporal patterns of visitation to all national parks in the country. National parks were selected as they are not only important protected areas for the conservation of biodiversity but are well recognised as one of the prime attractions for international tourists visiting New Zealand. Data are used to answer the following questions:

1. What proportion of international visitors include at least one national park in their travel itinerary and are they more likely to visit certain national parks?
2. Of these international visitors, what is the average number of national parks they visit?
3. How are national parks connected through the network of visits and do some form distinct spatial hubs or clusters?
4. Knowing that different nationalities exhibit marked variation in travel itineraries, to what extent can variation in the number of national parks visited be explained by tourist nationalities?
5. Do different nationalities pose a distinct risk of introducing alien species into national parks through being more likely to camp or stay overnight at Department of Conservation huts?

The extent to which these trends are generalisable were examined by comparing the movement network immediately prior to the closure of international borders in response to the SARS-CoV-2 pandemic and in the period following the relaxation of international travel restrictions (Fig. 1). If a significant proportion of international tourists visit national parks, travel to several national parks, and are likely to choose to camp, then it might suggest a high risk of alien species introductions through this pathway. If patterns are consistent pre- and post- border closures this

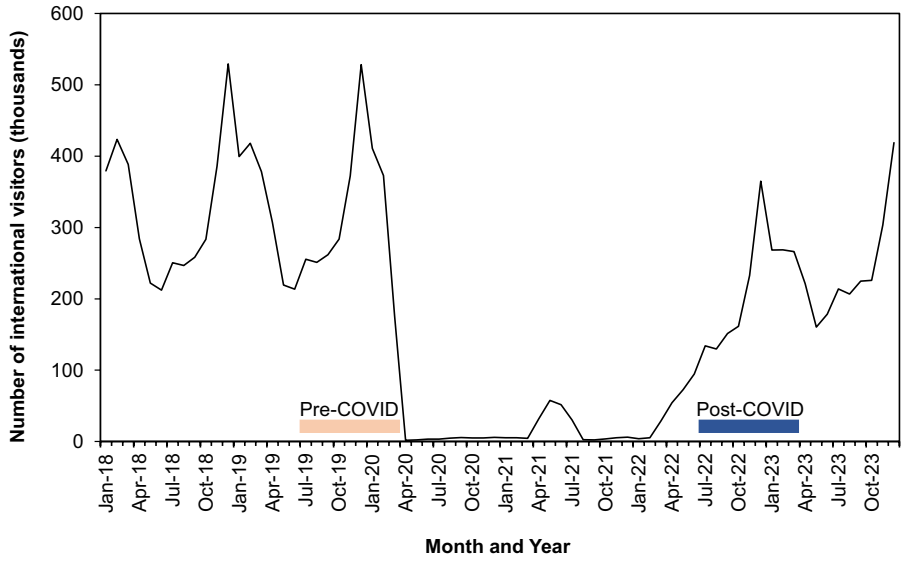

Fig. 1 The number of international visitors arriving each month in New Zealand between January 2018 and December 2023. Data from Stats NZ (https://infoshare.stats.govt.nz/). The two sampling periods of the International Visitor Survey (IVS) are depicted on the figures highlighting the 9-month sample in 2019 (light shading, pre-COVID) immediately prior to the closure of the international border and the 9-month sample in 2022 (dark shading post-COVID) that immediately followed the resumption of the IVS

might indicate a level of predictability that would facilitate the implementation of targeted surveillance to detect risks arising from international tourism.

Methods

New Zealand national parks

The 13 national parks in New Zealand encompass a wide range of landscapes from alpine to coastal ecosystems (Table 1). National parks receive the highest level of protection of any protected area in New Zealand and have been established to preserve in perpetuity areas of New Zealand that contain scenery of such distinctive quality, ecological systems, or natural features so beautiful, unique, or scientifically important that their preservation is in the national interest (Parliamentary Counsel Office 2023). Nevertheless, the benefit, use, and enjoyment of the public is also of paramount importance and thus national parks include networks of regularly maintained walking trails, mountain huts (both public and private), campsites and in several cases even ski fields (Roxburgh 2013). National parks are a major drawcard for international tourists visiting New Zealand and tourism is an important source of employment and income for the surrounding communities (Department of Conservation 2006). However, the management plans of all national parks have to specifically prevent the introduction of alien species or the further spread of such species within the national park both from visitors themselves as well as from the infrastructure that supports tourism (New Zealand Conservation Authority 2005).

New Zealand international visitor survey

The data on tourist behaviour was drawn from the New Zealand International Visitor Survey (IVS), which is run by the Ministry of Business, Innovation and Employment as a continuous exit survey primarily to provide accurate, quarterly, national information on the expenditure of international visitors to New Zealand, as well as their behaviours and characteristics (Ministry of Business Innovation and Employment 2024a). Following globally agreed standards, international visitors are defined as: persons who

Table 1 Details of the 13 National Parks in New Zealand

National Park	Area km^2	Established	DOC huts	Description
Abel Tasman	237	1942	7	Costal landscape with many tidal inlets and beaches but forest vegetation highly modified
Aoraki/Mount Cook	722	1953	16	Alpine landscape containing some of New Zealand's highest mountains and largest glaciers
Arthur's Pass	1,185	1929	28	Montane landscape spanning the Southern Alps but bisected by a major highway and railway
Egmont	342	1900	8	Largely comprises the forested slopes and alpine peak of the dormant volcano Mt Taranaki
Fiordland	12,607	1952	51	From coastal fiords to alpine peaks with large regions remote and difficult to access
Kahurangi	4,529	1996	51	Limestone landscape running from coast to the peak of Mt Owen (1,875 m)
Mount Aspiring	3,562	1964	19	A glaciated mountain landscape rising to 3,033 m
Nelson Lakes	1,019	1956	20	Mountainous area with forested slopes surrounding alpine lakes
Paparoa	430	1987	2	Limestone country clothed in rainforest
Rakiura	1,400	2002	24	Comprises most of Stewart Island, with largely unmodified coastal and montane landscapes
Tongariro	786	1887	10	Largely an alpine landscape containing three active volcanoes
Westland Tai Poutini	1,320	1960	12	Ranges from coastal to the high peaks of the Southern Alps, famed for its glaciers
Whanganui	742	1986	5	Borders either side of the Whanganui River with large tracts of lowland native forest

travel to a country other than that in which they have their residence, but outside their usual environment, for a period not exceeding 12 months and whose main purpose of visit is other than the exercise of an activity remunerated from within the country visited (World Tourism Organisation 2010). A minimum of 8,900 international visitors to New Zealand are sampled per year to ensure a 10% relative margin of error for each of the top six country markets (Australia, China, USA, UK, Germany, Japan). Among many other questions, interviewees are asked to provide details of any of the 13 national parks visited during their stay in New Zealand as well as the type of accommodation used. This included information on whether visitors stayed at private campsites, DOC huts or campsites, or freedom camped (no-fee campsites). There was no indication in the IVS of where camping took place, thus this measure only indicates a propensity for visitors to camp or stay in huts in national parks rather than direct evidence. Data were compiled from interviews undertaken in the nine months immediately prior to the SARS-CoV-2 border closures to international visitors (July 2019 to March 2020 inclusive) and the corresponding nine months following the resumption of international travel and the IVS survey (July 2022 to March 2023 inclusive). A total of 5,627 interviews were undertaken before border closures were imposed (hereafter described as the pre-COVID sample) whereas following the re-opening of the border 6,996 interviews were undertaken (hereafter described as the post-COVID sample). Unfortunately there are no comparable contemporary surveys for domestic tourists following termination of the New Zealand Domestic Travel Survey in 2012 (Parliamentary Commissioner for the Environment 2019).

Data analysis

The IVS data on interviewee activities were screened to identify those individuals who had visited at least one of the 13 national parks. For each interviewee, their nationality, the number and identity of national parks visited, and the frequency with which they used private campsites or motor camps, DOC huts or campsites, or freedom camped were extracted. Data derived from the IVS did not conform to the assumptions necessary for parametric analysis thus distribution-free methods (χ^2, median test, Spearman ρ, and Wilcoxon signed ranked tests) were applied to the data using JASP 0.18.3 (JASP 2024).

For each of the individuals interviewed, the identity of all national parks visited during their visit to New Zealand was recorded and where interviewees visited more than one national park this was interpreted as a link between these locations. By compiling the links between national parks created by visitors, it was possible to generate a visitation network for each of the two sampling periods. Association strength was selected as a probabilistic-based similarity measure to normalize the visitor networks for visualization, using the weighted degree as the strength of each link. The association strength compares the number of observed links between two national parks against the null expectation if links were randomly distributed to give an indication of how strong the relation is between a pair of national parks (Steijn 2021). National parks were clustered using a smart local moving algorithm to identify community structure with high modularity values and depicted using the "visualization of similarities" distance-based mapping technique using VOSviewer 1.6.20 (van Eck and Waltman 2010). Since the clustering of national parks arising from shared itineraries among international visitors could reflect their spatial proximity (likelihood that two national parks are more likely to be visited if they are close together), the approximate road distance between each national park was estimated using the New Zealand Automobile Association travel distance calculator (www.aa.co.nz/travel/time-and-distance-calculator/). Road distance was the preferred measure as several national parks are adjacent to each other but lie either side of the Southern Alps mountain range which makes ground travel between the national parks almost impossible to all but experienced mountaineers.

Results

Most international visitors who enter national parks in New Zealand visit at least two parks and for some well-represented nationalities the median number of national parks visited can be as high as five. As might be expected there is a long tail to the frequency distribution of the number of national parks visited by an individual international visitor highlighting the variable risk arising from tourists spreading alien species.

Those nationalities that had higher frequencies of visits to different national park were also those most likely to camp or use mountain huts. Thus, based on indirect evidence describing visitation frequency as well as information on their propensity to camp or stay in mountain huts, it is anticipated that European visitors likely pose the highest risk of introducing and spreading alien species to protected areas in New Zealand.

The total number of international visitors arriving in New Zealand declined following the reopening of the international border in 2022, though highlighted similar seasonal patterns (Fig. 1). Even so, visiting a national park was a frequent activity of international visitors with a total of 3,499 (62.18%) and 3,039 (43.44%) interviewees stating they had done so in the pre- and post-COVID samples, respectively. Nevertheless, the proportion of interviewees stating they had visited a national park dropped by almost one-third between the two sample periods ($\chi^2 = 438.76$, df 1, $p < 0.001$). Not all international visitors surveyed were able to give the name of the national parks they had visited and thus the following analyses are based on the sample of interviewees that provided this more specific detail (sample sizes: pre-COVID = 2514 and post-COVD = 2435).

There were marked differences in the frequency with which different nationalities were represented in the two sample periods ($\chi^2 = 586.38$, df 9, $p < 0.0001$) with significantly fewer visitors from Japan, China, and Korea visiting a national park post-COVID but with a corresponding increase in Australian and British nationals (Fig. 2a). In addition, the frequency with which the different national parks were visited differed between the two sample periods ($\chi^2 = 214.64$, df 12, $p < 0.001$). Post-COVID, fewer interviewees visited Mt Aspiring or Paparoa National Parks while both Arthur's Pass and Westland National Parks increased in relative visitation frequency (Fig. 3a). Despite these differences, the two most visited national parks remained the same (Fiordland and Aoraki/Mt Cook) as were the two least visited (Rakiura and Kahurangi) and the frequency of visits across all the national parks was similar between the two sample periods (Spearman $\rho = 0.85$, df 11, $p < 0.001$).

Although differences existed in the frequency with which different national parks were visited between the two sample periods, the behaviour of international visitors in terms of the number of national parks they

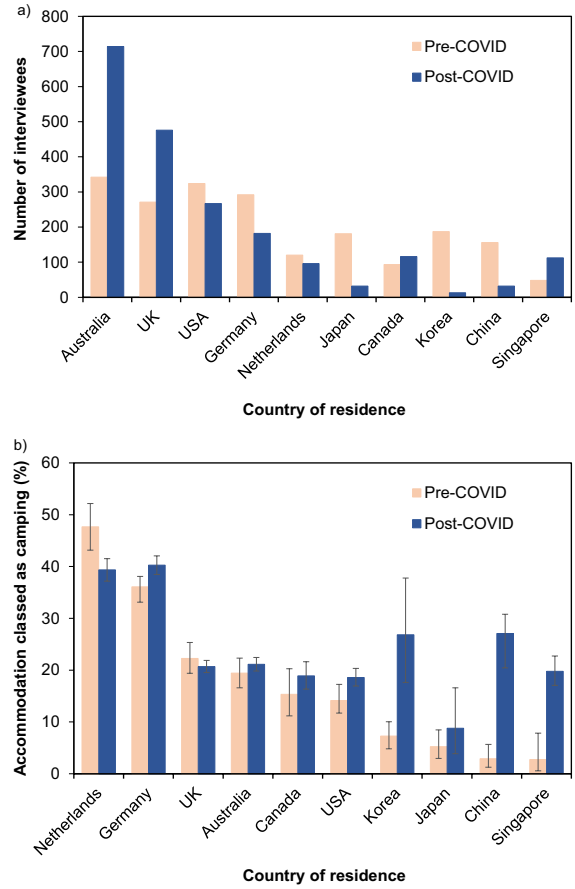

Fig. 2 Variation among the top 10 international visitor nationalities to New Zealand during the pre- and post-COVID sample periods in terms of **a** the frequency they visited at least one national park and **b** the percentage of accommodation choices made by national park visitors that could be classed as camping (which is interpreted here to include using camping and campervan sites, freedom camping, and staying at DOC huts). Error bars are 95% binomial confidence intervals

each visited was similar ($\chi^2 = 13.52$, df 11, $p > 0.05$). The number of visits was strongly right skewed, with more than half of international tourists visiting two or fewer national parks (Fig. 3b). For both pre- and post-COVID sample periods the number of national parks visited by an international visitor was correlated with the length of their stay in New Zealand, though the variance explained was low (Spearman $\rho = -0.34$, df 2011 and 0.35, df 2040, both $p < 0.001$ for pre- and post-COVID respectively). There was significant heterogeneity in the frequency with which national parks were visited by the main nationalities of visitors. Ten nationalities accounted for over 80% of all

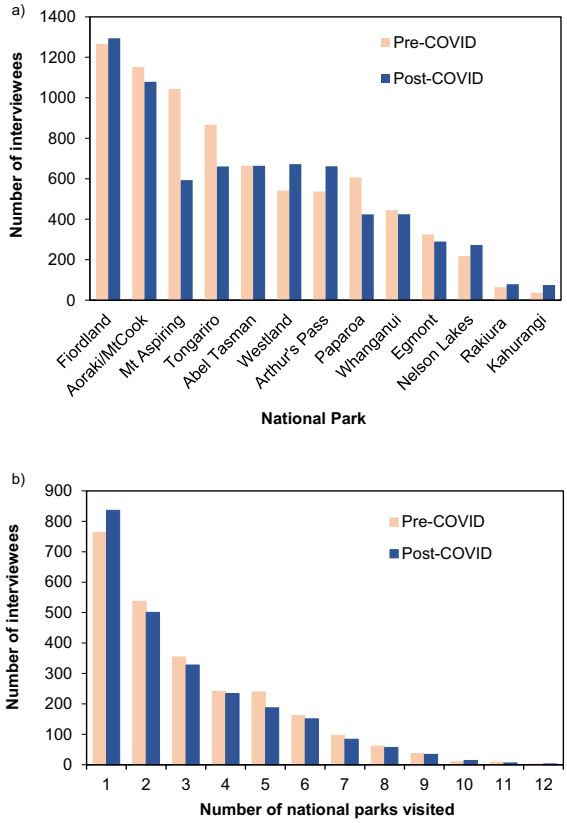

Fig. 3 Variation in the frequency with which of international visitors to New Zealand **a** visited different national parks and **b** visited different numbers of national parks. Data are presented separately for the pre- and post-COVID sampling periods

international visitors to national parks in both pre- and post-COVID samples, with residents of Australia, the UK, and USA the most frequent. Although visiting in fewer numbers, residents of Singapore, Germany, and the Netherlands generally visited more national parks than visitors from other countries (Median test statistic = 344.07, df 9, $p < 0.001$, Fig. 4).

Visitors belonging to the top 10 nationalities also differed in the extent they stayed at campsites, motor camps, DOC huts, or freedom camped both during the pre-COVID ($\chi^2 = 516.97$, df 9, $p < 0.0001$) and post-COVID ($\chi^2 = 724.85$, df 9, $p < 0.0001$) sample periods. Overall, visitors from Asian and North American countries were less likely to camp than those from Europe, with the Dutch and Germans most likely to do so (Fig. 2b). The marked increase in the percentage of accommodation choices classed as camping by Asian nationals in the post-COVID sampling period is primarily an artefact of the very small number of visitors from these countries.

The national park visitor network was fully connected with at least one link between every node (Fig. 5). In both the pre- and post-COVID networks, there were three clear clusters of national parks. These roughly corresponded to geographic boundaries with the three North Island national parks being clustered separately from those in the South Island. In the South Island, the national parks to the east of the Alpine fault (a geological feature that runs almost the entire length along the mountainous spine of the South Island) were generally clustered separately from those of the west. However, while the number of international tourists that visited any two national parks was negatively correlated with the road distance between them, the relationship was not especially strong (Spearman $\rho = -0.191$ df 76, $p = 0.09$ and -0.231 df 76, $p = 0.042$ for pre- and post-COVID samples respectively).

Discussion

A significant proportion of international visitors to New Zealand visit national parks and of those that do, two-thirds visit two or more national parks and thus travel relatively long distances across the country during a comparatively short visitation period. Thus, given their large numbers, it is certainly possible that international visitors could bring biosecurity risk material from overseas into national parks. Importantly though, the climates of the 13 national parks are much less favourable to the establishment of alien species than most of New Zealand, with their largely montane landscapes favouring species from cooler, wetter regions of western Europe, southern Iceland, Patagonia, and south-eastern Australia (Phillips et al. 2018). Thus, groups potentially posing a higher risk of introducing alien species from overseas into national parks will include British, German, and Dutch nationals due to their reasonably high visitor frequency to national parks, propensity to camp or stay at DOC huts, and stronger climate match of their country of residence. This is in stark contrast to the profiling of international visitors arriving at the New Zealand border that identifies Chinese and Indian nationals as posing the highest risk of bringing biosecurity

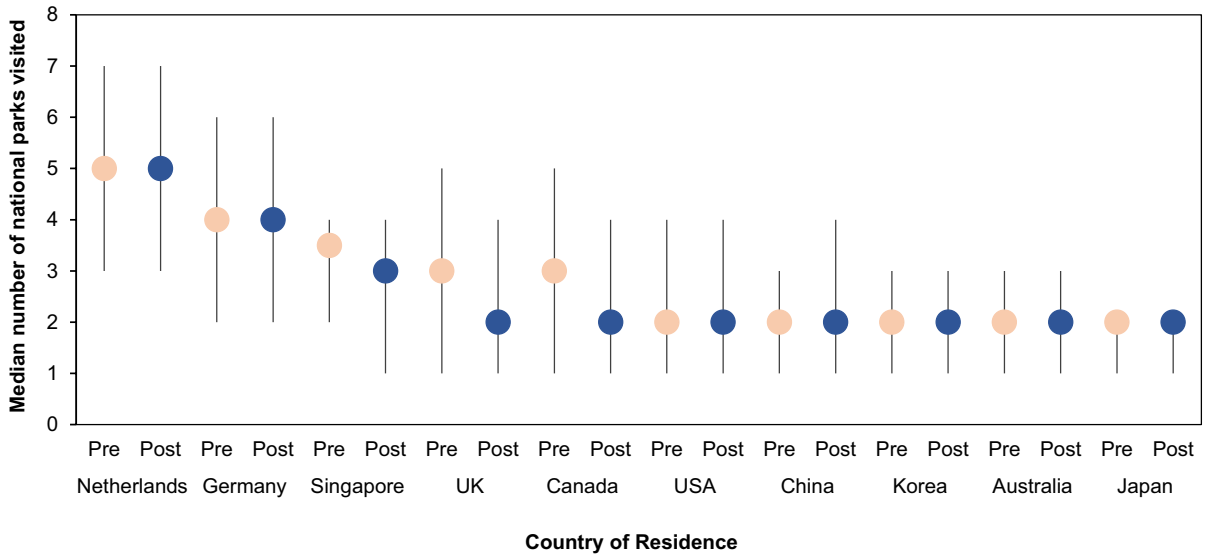

Fig. 4 Variation in the median number of national parks visited in New Zealand by the top 10 international visitor nationalities during the pre- and post-COVID sample periods. The data represent the median and the interquartile range of the number of national parks visited by each nationality

risk material (Sherring 2020). This likely reflects a greater focus at the border on managing biosecurity threats to agricultural production stemming from the introduction of plant and animal products than from contaminated outdoor recreational gear.

In addition to the investment in border biosecurity in New Zealand, the Ministry for Primary Industries has implemented a high-risk site surveillance programme that includes surveys of several campsites in national parks (Acosta et al. 2020). How effective such surveillance is at picking up cryptic organisms is unclear. Although historically, national parks have not always been the first locations visited by international visitors (Forer and McNeill 2008), the increase in freedom camping by international tourists, where the accommodation is a camper van, may lead to a greater risk of transferring alien species from tents, clothing, or footwear into protected areas in New Zealand (Fieger et al. 2020). While the risk from international visitors bringing alien species from overseas directly into a national park may be restricted to nationalities arriving from climatically suitable areas and likely to freedom camp, direct evidence where this has unequivocally happened is scant. The introduction from overseas of more cryptic species such as soil mites or microbes will largely be missed unless they have marked effects on ecosystems (such as plant pathogens).

International tourists can still be responsible for the movement of established alien pathogen, pest, and weed species around the country. The bioclimate of the national parks also acts as a strong filter on the establishment of some invertebrate taxa such as alien ants that can often be accidentally transported by visitors but have as yet failed to establish in New Zealand national parks (Phillips et al. 2018). This is likely to be true of poikilotherms such as fungi, plants, invertebrates and reptiles (Wagner et al. 2023). Whereas climatic filtering was an important aspect reducing the potential risk of alien species from overseas establishing in national parks, it is likely to be less of a barrier in terms of the movement of species among different national parks many of which have similar cool, wet, montane environments. Although three geographic clusters of national parks were identified, every national park was connected to every other by international visitor movements suggesting alien species could be easily dispersed across the national park network.

The patterns in the visitation frequency to national, parks are consistent with the high mobility of international visitors over the relatively short time periods they are visiting New Zealand (Becken and

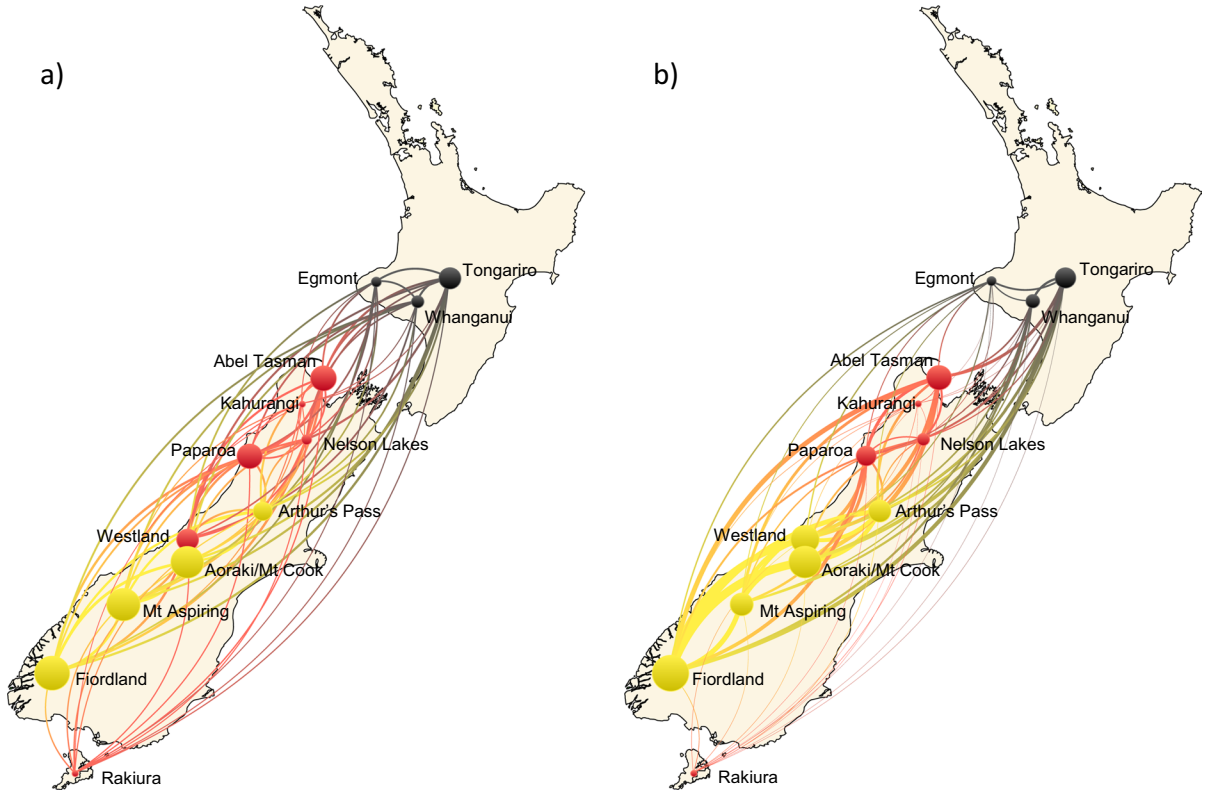

Fig. 5 Depiction of the international visitor travel network across all 13 national parks in New Zealand highlighting the strength of the links between different National Parks (line width) and the popularity of individual national parks (node size). Three geographically distinct national park clusters can be seen in both the **a** pre-COVID sample (cluster 1: Egmont, Tongariro, Whanganui; cluster 2: Abel Tasman, Kahurangi, Nelson Lakes, Paparoa, Rakiura, Westland; cluster 3: Aoraki, Arthurs Pass, Fiordland, Mt Aspiring) and the **b** post-COVID sample (cluster 1: Egmont, Tongariro, Whanganui; cluster 2: Abel Tasman, Kahurangi, Nelson Lakes, Paparoa, Rakiura, cluster 3: Aoraki, Arthurs Pass, Fiordland, Mt Aspiring, Westland)

Schiff 2011; Forer and McNeill 2008). During the 2022–2023 summer, 68% of international visitors participated in a walk and the majority of these walks were longer than 30 min, with 22% over 3 h (Department of Conservation 2023). Thus, international visitors certainly have the potential to vector alien species from one national park to another as well as further disseminating species already present in national parks.

Small-seeded plant species that maintain a persistent soil seed bank may be easily picked up in mud on footwear or camping equipment and transported to other locations. For example, European heather (*Calluna vulgaris*) was first introduced to New Zealand for planting in Tongariro National Park in the early twentieth century where it subsequently naturalised extensively and can now be found in several national parks including Aoraki/Mt Cook, Egmont, and Fiordland (Webb et al. 1988). It has also begun to appear in Arthur's Pass where it is associated with walking trails implicating visitors to the park as potential dispersal agents (personal observation). Tussock hawkweed (*Hieracium lepidulum*) is locally present in Fiordland, Aoraki/Mt Cook, Arthur's Pass, and Nelson Lakes National Parks but in the North Island is currently only found in the alpine tussock lands of Egmont National Park (Wiser and Allen 2000) but could easily be transported on footwear to similar ecosystems in Tongariro National Park. Although bird-dispersed, the small seeds and persistent seed bank of Chilean rhubarb (*Gunnera tinctoria*) also allow the species to be spread through soil movement on footwear or camping equipment (Gioria and Osborne 2013) and while the species has a limited

distribution in both Paparoa and Kahurangi National Parks and has been locally eradicated from Egmont National Park, it is relatively common outside of these protected areas (Williams et al. 2005).

The balance of evidence suggests the risk of disseminating alien species already established in New Zealand (including in other national parks) into national parks is more likely than introducing alien species from overseas. This is partly due to the bioclimatic constraints on alien species establishment in national parks but also the biosecurity interventions undertaken at the border. Education of international tourists of the risk posed by alien species to the integrity of national parks would seem to be an essential action to mitigate this risk, yet such initiatives have not received sufficient attention and investment to be effective. To limit the risk of introducing alien species from overseas, in-flight videos, arrival cards, and signage at the destination airport has helped drive behavioural change among international tourists through a declare or dispose programme (Sherring 2020). However, pre-arrival awareness raising should stress the risk to biodiversity from alien pests, weeds and pathogens more strongly than at present. Visitor education post-border can work well when initiatives raise awareness among tourists about a particular alien species, such as with didymo and the "Say No to Didymo" campaign that encouraged recreational users of waterways to check, clean or dry their equipment to prevent the spread of this invasive alien diatom. Such initiatives need to be supported by a strong social marketing approach and long-term funding. Education is not only important for international visitors but also for the tourism operators that have concessions to undertake activities in national parks but the evidence to date from high latitude cruise-operators and wineries suggests adoption rates by the tourism industry can often be low (Hall 2015).

Provision of signage regarding biosecurity threats posed by visitors should be prominently displayed at the start of walking trails and in campsites, as well as associated with boot cleaning stations. Such messaging should aim to motivate international visitors to become guardians of the natural environment. by engaging with them regarding the threats posed by invasive alien species to biodiversity. At the same time, the monitoring of alien species, particularly alien plants along walking trails, in campsites, and around DOC huts is recommended so that emerging problem species can be identified early, and action taken to prevent their wider establishment. As a start, targeting the New Zealand Great Walks for improved signage, awareness raising materials (in multiple languages) and boot cleaning stations might be an effective first step to reduce this potential pathway of alien species invasions into national parks. Since 2019, most international visitors to New Zealand are charged an International Visitor Conservation and Tourism Levy (IVL) of NZ$35, that aims to fund sustainable tourism and protect the environment. From October 2024, the IVL will increase to $100 potentially raising over $200 million per year for important tourism and conservation initiatives. In the past, these funds have been used for specific conservation projects, investment in tourism infrastructure, as well as international marketing (Ministry of Business Innovation and Employment 2024b). However, in the future the IVL should also be used to improve biosecurity perceptions of international tourists and tourism concessionaires to reduce the risk of introducing alien species into protected areas.

While this study is especially relevant to the issue of biological invasions in New Zealand, the findings have wider implications for the delivery of several of the Kunming-Montreal Biodiversity Framework Targets. In addition to Target 6 that specifically addresses invasive species, the explicit consideration of the tourism pathway and ways to mitigate this risk should be a key factor when designing or reviewing protected area management plans (Target 1) and should ensure that tourism operators comply with codes of conduct that minimise the biosecurity risks their activities might pose to biodiversity and ecosystem services (Target 15). But to achieve such an outcome will require appropriate assessment of these risks through interdisciplinary research that not only quantifies the scale of the risk from this pathway (e.g., though boot, tent or clothing cleaning) but also works towards behavioural change among visitors so they recognise the potential risks they pose (Target 21). The funding of this research and associated interventions (including the costs of awareness raising signage and boot cleaning stations) could be supported through national or local tourism levies as well as the concession fees of tourism operators (Target 19). With the growth of international tourism picking up quickly after the hiatus of global lockdowns (UNWTO 2024), implementing these aspects of the Kunming-Montreal

Global Biodiversity Framework would appear to be a priority for protected area managers worldwide.

Acknowledgements The author is grateful for the opportunity to present this work at the Workshop on Biological Invasions in Protected Areas held in Stellenbosch, South Africa in April 2024.

Authors' contributions P.E.H. obtained the funding, planned and designed the research analysed the data and wrote the manuscript.

Funding Open Access funding enabled and organized by CAUL and its Member Institutions. Funding was provided from the Tertiary Education Commission of New Zealand to Bioprotection Aotearoa.

Availability of data and material International Visitor Survey data are publicly available from https://www.mbie.govt.nz/immigration-and-tourism/tourism-research-and-data/tourism-data-releases/international-visitor-survey-ivs/. Data on bookings for New Zealand Great Walks are available from https://www.doc.govt.nz/about-us/our-role/managing-conservation/recreation-management/great-walks-management/great-walks-visitor-numbers/.

Declarations

Conflict of interest The authors declare no conflicts of interest or competing interests.

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