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RESEARCH

Surveying knowledge production in New Zealand ecology: towards a resilient publication system

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Abstract: Scientific knowledge production in the form of scientific publication is an increasingly connected and global endeavour, and institutional and funding pressures make it likely that studies addressing local questions may become less frequent and less obvious in the literature. We used the Scopus database and a focused subset of research published in ecological journals to evaluate trends in scientific publishing in New Zealand from 1980–2020 in the broad field of biological and environmental sciences. We evaluated research on New Zealand's ecological systems by authors affiliated with a New Zealand institution and published in an ecological journal. In some ways, these bodies of research reflect widespread trends in science: increasing productivity, larger author teams, and increasing international connectivity. However, published research about New Zealand's ecological systems has slowed compared to biological and environmental research published by New Zealand scholars. There have been changes through time in the subjects considered. For example, New Zealand-focused ecological publications have increasingly emphasised conservation and invasion biology. Likewise, there have been shifts in collaborations between different groups of institutes (e.g. universities and Crown Research Institutes) and the amount of research published by them. One outcome of these changes has been the development of a distinctive local literature (i.e. specific topics have retreated to local journals, while others have become internationalised). We conclude by considering some potential challenges that local journals face in the current publishing environment, and how a more resilient local ecological publishing community might be developed.

Keywords: ecology, science reform, scientific publishing, structural topic models, text analysis

Introduction

The body of knowledge produced by a community as represented in scholarly publications provides a lens into how scientific interests and organisational structures have changed over time. Syntheses of global scientific literature have revealed some pervasive trends, including exponential increases in the rate of production, rapid growth in the size of authorship teams (Park et al. 2023), and, possibly, declines in the number of individual studies leading to radical change (disruptive *sensu* Park et al. 2023). The massive acceleration in science publication in the post-World War II period has been attributed to increased pressure to publish and fundamental shifts in how science is organised and funded (Bornmann et al. 2021). However, these trends vary with discipline and location; some disciplines are growing in publication rate more quickly than others (Wang & Barabási 2021), and the production of science is geographically variable (Doi & Takahara 2016; Collyer 2018). In some disciplines, concerns have been raised about the future of local journals in this internationalised environment (Ofori-Adjei et al. 2006). Thus, from both an administrative and scientist viewpoint it is worthwhile attempting to understand how and why publication practices are changing.

A particular focus of the 'science of science' (Fortunato et al. 2018; Wang & Barabási 2021) has been how collaboration structures emerge and evolve in scientific communities. Pioneering work on the nature of scientific collaboration (Newman 2001, 2004a) suggested collaboration networks tend to follow 'small world' structure where, even in a large community, the number of links between any two authors is surprisingly small. Other studies have explored how much collaboration influences a publication's impact, with mixed results. Katz and Hicks (1997) suggest that collaborations increase impact, with the effect stronger for international links. Conversely, Leimu & Koricheva (2005) reported a positive impact of inter-institution collaboration, but not international collaboration (looking solely at the ecological journal *Oecologia*), and more recent studies (Petersen 2015) have suggested these dynamics shift with an individual author's career stage. Despite impact factors being a narrow and problematic lens on the quality of science, these studies reveal some of the drivers of knowledge production and dissemination in scientific communities.

Although metrics such as publication rate are one measure

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of scientific publication, they are partial and do not capture the cognitive extent or interest of a field (Milojević 2015). As Milojević argues, the rate of change in the number of publications in a field is not the same as change in the number of ideas. For example, the ecological literature has grown rapidly in recent decades (Knott et al. 2019; Anderson et al. 2021) but arguably the key components of the discipline have been in place since the 1950s, even if they have not been adequately identified or integrated (Scheiner & Willig 2008). However, large collections of scientific literature can be used to identify trends in the topics on which a scholarly community focuses. Machine-learning models trained to provide unsupervised classifications of large collections of documents (corpora) have facilitated this process (Westgate et al. 2015). Such efforts have several goals, including describing trends in the foci of a given discipline, informing investment in research funding, assisting authors to formulate publication strategies, and identifying knowledge gaps (Knott et al. 2019; McCallen et al. 2019; Lee et al. 2023).

Several reviews have addressed changes in the dominant themes in the discipline of ecology (Neff & Corley 2009; Carmel et al. 2013; McCallen et al. 2019; Anderson et al. 2021; Zettlemoyer et al. 2023). While these studies consider different bodies of literature and employ different methods, they identify a common trend over the last 50 years in ecology, summarised by McCallen et al. (2019, p. 113) as a shift from "classical, plant-, and population-oriented themes to more contemporary microscale, macroscale, and anthropogenic themes". Or, as Neff and Corley (2009) and Carmel et al. (2013) describe it, towards a "policy-relevant" or "problem solving" discipline. While ecology is often viewed as a dynamic science, Carmel et al. (2013, p. 7) suggest the opposite, reporting little change in the topics they self-identified as the most important in ecology. They instead conclude that "the science of ecology appears to be changing slowly". Again, topics identified via text analysis are only a partial insight into changes in a discipline's cognitive extent; for example, it may also be that the fundamental questions of ecologists may not have changed (i.e. the topics are stable) but that the way these questions are framed and articulated, and the methods used to answer them, have.

Parallel to thematic trends are shifts in methodology, some a function of changes in technology (especially those permitting access to hitherto unquantified or invisible factors leading to new types of enquiry) and others responding to climate change and biodiversity loss (Thompson et al. 2001). As Anderson et al. (2021, p. 278) note, "Ecology has increasingly become a data- and model-centric discipline". This trend is evident in some longitudinal analyses of how ecology is conducted. For example, Ríos-Saldaña et al. (2018) describe around a 20% decline in field-based publications (1980–2014) in conservation biology while modelling and data analysis studies increased by 600% and 800%, which in their view was undermining the empirical basis of the discipline. On the other hand, Carmel et al. (2013) reported that across ecology, observational studies remain dominant, with no change in the prevalence of modelling studies from 1981 to 2010.

A handful of recent studies have considered long-term trends in ecological science in New Zealand and Australia. Westgate et al. (2020) reviewed publications in *Austral Ecology* (formerly the *Australian Journal of Ecology*) from 1976–2019. They described shifts in key themes in the journal's publications similar to those identified in global studies: a move from single-species and site studies to community and ecosystem-level studies using modern quantitative methods. However, some of the specific topics they identify represent the journal's geographic context, such as the strong focus on fire ecology and the effects of invasive mammals on trophic flows. Similarly, Perry and McGlone (2021) surveyed nearly six decades of publications in the *New Zealand Journal of Ecology* and its predecessors. They described shifts in some of the topics, following global trends, but also that the journal has consistently focused on applied topics surrounding animal species control, even if the taxa of interest have shifted over time (deer > possums > rodents > mustelids > multi-species interactions). Thus, these two studies show that local communities of ecological knowledge production tend to follow macro-scale disciplinary trends, while also reflecting the specific contexts within which they work.

Here, we look at trends in the production and themes in ecological science about New Zealand (NZ) and by ecologists affiliated with NZ universities across all the relevant scientific journals in the Scopus database over the period 1980–2020 (rather than limited to specific journals as per Westgate et al. 2020; Perry & McGlone 2021). To this end, we use a combination of visual exploration, co-occurrence analyses, and structural topic models. We start by comparing trends in these ecological corpora to the areas of which they are a subset (agricultural/biological sciences and environmental sciences) before looking at the thematic evolution of ecological science in NZ. We focus on three broad questions: (1) how have patterns of scientific publication (rates, collaborations) by NZ ecologists changed over the period 1980–2020? (2) how have the thematic foci of NZ ecologists and NZ ecological research changed over this time? (3) how do any changes relate to structural changes in the NZ science or funding system, and what are their implications for the resilience of NZ's local ecological journals?

Methods

Data sources

We used the Scopus database (Baas et al. 2020). For papers published concerning NZ ecology we started by searching Scopus on articles containing "New Zealand" in the TITLE-ABSTRACT-KEYWORD field, constrained to the AGRI (agricultural/biological sciences) and ENVI (environmental science) subject areas (date: 07/12/2022). For papers published *by* ecologists based in NZ we repeated the search but with affiliation country of "New Zealand" and no TITLE-ABSTRACT-KEYWORD constraint. These searches gave us data for the agricultural and biological sciences and the environmental sciences as defined by Scopus. We created a subset of these corpora by filtering out records in journals belonging to the ecology category in the Journal Citation Report or listed by Réale et al. (2020). We screened for duplicate records using the article's digital object identifier (where available) and title, and the risk of duplication was mitigated by using a single database. We also limited the corpus to articles: (1) published post-1979, (2) published in journals (including reviews, short notes, etc., but excluding errata, editorial, obituaries, etc.) and (3) in English. We used the franc package v 1.1-4 in R to identify potential non-English abstracts and then screened them manually. Although only considering English can impose biases in systematic reviews (Konno et al. 2020; Zenni et al. 2023), given our focus on NZ this is unlikely to be a significant issue. We used the English version for abstracts presented in more than one language. Although Scopus has broad coverage of the science literature, our corpora are not exhaustive; however, other studies have shown high overlap between Scopus and other databases (e.g. Web of Science) for journal articles (Visser et al. 2021). Given the large corpora we work with, we assume they capture the general trends in the NZ science landscape.

Analysis

Our analyses comprise a descriptive (visual) component and formal topic modelling via structural topic models (Roberts et al. 2019) to identify dominant themes in the corpora and how they have changed over time. As a first step, we were interested in change through time in the rate of production of literature about NZ ecology by NZ-affiliated ecologists and where this research is published relative to the broad agricultural/biological and environmental sciences of which ecology is a subset. We then focused on the subset of publications that we classified as ecological, looking at three corpora: publications about NZ ecology (topic corpus), ecological publications with at least one co-author based in a NZ research centre (affiliation corpus), and the two combined (combined corpus). An article may appear in both the topic corpus and affiliation corpus (i.e. a publication considering NZ by NZ-affiliated authors). For these three corpora, we focused on the social structure (affiliation and individual) and geography of author collaboration, themes in the literature as expressed through keywords, and relationships between these themes as expressed in networks. Finally, we built structural topic models (STMs) for each of the three corpora with a fixed number of topics ($k = 24$, see below) fitting time (year) and whether the paper appeared in a NZ journal as document-level covariates. We also built STMs for NZ journals and international journals using the combined corpus. All analyses were conducted using R version 4.3.1 (R Core Team 2023) and a full list of packages used, version numbers, and their authors is provided as Appendix S1 in Supplementary Material.

Visual analysis

We extracted descriptive data including publication numbers over time, journals published in (NZ vs. international), author team size, and author affiliation to describe trends in productivity and collaboration. We built networks for keyword pairs and co-authorships (at affiliation and individual level) and clustered these using the Louvain algorithm (Blondel et al. 2008); we also looked at the trajectory of these networks over time (by topic and affiliation). Finally, we built geographic networks for collaborations across countries. In all networks, links were weighted (w_{ij}) following Newman (2004b) as:

$$w_{ij} = \sum_k \frac{\delta_i^k \delta_j^k}{n_k - 1} \quad (1)$$

where δ_j^k is one where author i was an author on article k (zero otherwise) and n_k is the number of authors on the article (single authored articles are not considered).

Structural topic models

We used structural topic models (STMs) to identify topics in the abstracts (Roberts et al. 2019). In a STM, terms (e.g. words) are allocated to a single topic, and the proportion of terms in a document coming from each of the k topics is calculated; hence each body of text (in this case an abstract) is associated with the k topics. Structural Topic Models have the advantage over more widely used methods of topic modelling, such as Latent Dirichlet allocation, that they support the inclusion of document-level covariates. This model yields two parameters: b_k being the probability of a word arising from topic k, and g_k the proportion of words in a document associated with topic k (Silge & Robinson 2017); note that the STM package refers to g as theta. Thus, the approach is not a hard classification; rather, documents are blends of topics and topics blends of terms. We can estimate the effect of any covariates fitted to the model (this, for example, allows us to assess change over time in topic prevalence).

Text in the abstracts was lemmatised (i.e. inflections grouped) using the lexicon compiled by Michal Měchura (https://github.com/michmech). HTML tags, copyright statements, and stop-words (frequently recurring words with no contextual value for natural language analysis, such as ‘and’, ‘there’, ‘but’) were removed (for stop-words we used the standard list from SnowballC v 0.7-0 with custom additions for some other noninformative, ubiquitous terms; see Appendix S2). We created STMs using both unigrams and bigrams. Terms that appeared in a fraction fewer than 0.005 or more than 0.85 of the documents in a corpus were removed. The STMs were fitted using the R package STM version 1.3.6.1 (Roberts et al. 2019).

A key decision in implementing a topic model is the selection of the number of topics (k). We used the methods described by Wang et al. (2019) in which the terms in the corpus are encoded using text embedding (here the word2vec R package; Wijffels 2021) and the resultant embedding vectors clustered (using the method of Rodriguez & Laio (2014) to identify broad areas with similar vocabularies. For each corpus this approach estimated 20–24 broad areas, and so we set $k = 24$ for all. We estimated STMs with covariates of year, whether a document appeared in a NZ journal, and the interaction between the two. We looked at changes in the topics’ prevalence over time using the effects estimated from the STM models and the mean g value (probability of an abstract belonging to a topic) over time (higher g suggests more articles belong to that topic) and the number of articles allocated to each topic per year (based on highest g).

Results

After searching, filtering, and cleaning we assembled nine corpora (Table 1), comprising 81 649 unique documents; note that the same article could occur in more than one corpus. The ecology corpus contained 19 100 unique documents.

Trends in productivity, international publishing, and authorship teams

The number of publications in each of the eight corpora has grown exponentially over time, as has the size of authorship teams (Fig. 1). However, there are important differences between the different subject areas and the NZ-affiliated and NZ-topic groups. Although the agricultural and biological sciences (AGRI) group is the largest numerically, when normalised it is the environmental sciences (ENVI) that have grown most rapidly over the last 40 years (in both the topic corpus and affiliation corpus). Ecological publications with a NZ-affiliated author (affiliation corpus) have increased by a factor of 1.76 since 1980 (normalised value: 1.35 vs. 2.38), similar to the increase in publications with a NZ-topic (topic corpus; 1.73-fold increase; 0.56 vs. 0.97). However, in terms of absolute figures the number of publications on NZ ecological

Table 1. Size (number of documents) of each of the nine corpora after cleaning; note that the ecology corpora is a subset of the other two. Because some publications appear in more than one corpus, the total number of publications in a subject (total) is less than the sum of the other rows.

	Agricultural and biological sciences (AGRI)	**Environmental sciences (ENV)**	**Ecology**
NZ topic only (topic-corpus)	9415	3066	1834
NZ affiliation only (affiliation-corpus)	35 688	8265	7608
Number in topic-corpus and affiliation-corpus	20 936	4279	9658
Total unique (combined-corpus)	66 039	15 610	19 100

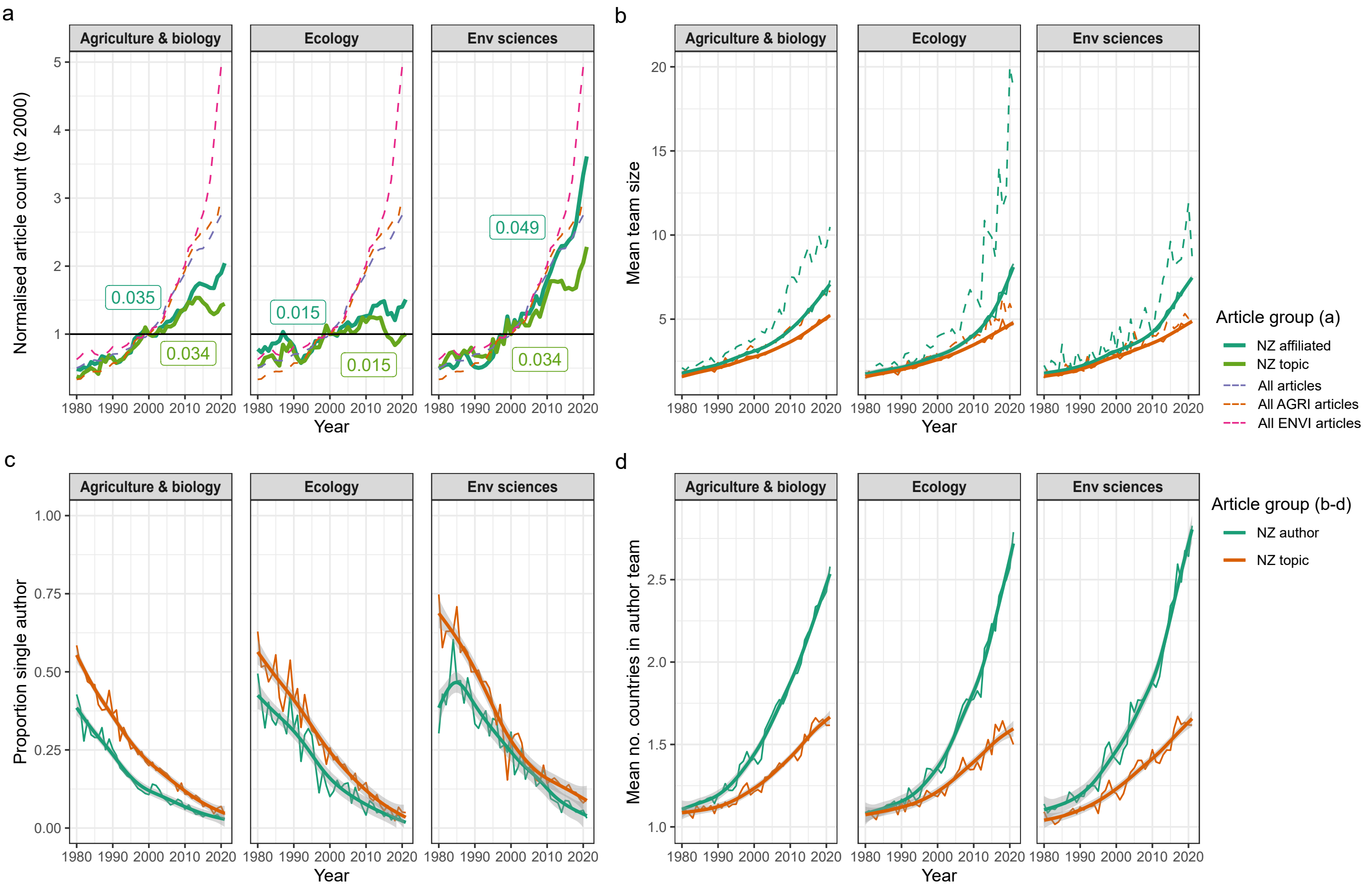

Figure 1. (a) Normalised article count over time (relative to 2000), labels in squares are exponential growth rate, (b) mean author team size (dashed lines shows publications above the median impact factor for that year), (c) proportion of publications with a single author, (d) mean number countries in author teams. Smoothers are general additive models in all cases, with grey shaded area the 95% confidence interval.

topics has changed little since 2000 (304 vs 294 publications in 2000 and 2020, respectively).

Fortunato et al. (2018) reported an increase of 17% per decade in the size of authorship teams across the sciences. This trend is evident in the corpora we investigated, although the rates of growth are slower than the global average and there is variation between subject areas and publications with a NZ-affiliation vs. NZ-topic. The number of ecological publications has grown more slowly than the number of publications in either the biological or environmental sciences (1% vs. 4%; Fig. 1a).

Following the observations of Wuchty et al. (2007) and Fortunato et al. (2018), more frequently cited papers tend to have larger author teams than the mean across all papers, with the differences greater for papers with NZ-affiliated authors than NZ-topics. There are striking temporal trends in the patterns of the rate of production and where research about NZ ecology and by NZ ecologists is published (NZ vs. international journals). The effects of changes in the NZ science system are evident; there was a strong dip in productivity in ecology in the early 1990s coincident with the time that the government-owned Crown Research Institutes (CRIs) were formed (Fig. 2b). The proportion of publications with an international author included have grown over time, with most such publications appearing in international journals (Fig. 2a); however, the proportion of publications without an international co-author has grown much less quickly and has declined in NZ journals. In 1980, 92.7% of ecological papers with at least one NZ-affiliated co-author comprised only NZ authors, and 79.9% of papers

Figure 2. Trends in productivity (a) and citation rate (b) in NZ ecology as a function of NZ (local) vs international journals and authorship teams with and without international collaborators and at least one NZ-affiliated co-author. Citation rates are expressed as field citation rate, which is the mean citation rate within a group relative to the overall average.

considering NZ topics comprised only NZ authors. By 2020 these figures had dropped to 53.2% and 56.4%, respectively. Overall, the number of ecological publications appearing in NZ (local) journals has declined nearly 50% (313 vs. 176) since 1980. Of those 313 papers appearing in NZ journals in 1980, 254 (81.1%) had only NZ authors; by 2020 this figure had dropped a little to 71.0% (125/176). In terms of the organisational affiliation of those publishing in local journals, since 2000 the contribution of CRIs and government agencies has slightly declined, whereas that of the universities has been stable (Appendix S4). Authorships in international journals have increased slightly in CRIs and government agencies over time, with strong increases in the university sector (more than doubled since 2010). Combined, these trends suggest a shift in the NZ ecological community from local author teams publishing in local journals to multi-country teams publishing in international journals, with NZ-affiliated authors publishing some work in local outlets.

In terms of citations rates, the ecological publications in international journals are consistently more highly cited than those in local journals, and those in international journals are cited more often if they have an international authorship team (Fig. 2b). Interestingly, the difference in the field cited ratio between international and local journals has declined over time for NZ-only author teams (Fig. 2b), perhaps suggesting (as per Fig. 1a) that papers focussed on NZ topics (assuming this is the focus of most papers by NZ-only teams) are increasingly being published in international journals.

Trends in co-author collaboration networks: geography, affiliation, and individuals

International geography of collaboration

The number of countries and author affiliations in the corpora increases exponentially over time (Appendix S5). In terms of research focussed on the ecology of NZ, geographic co-authorship interactions are strongest with Europe, the USA, and Australia (Fig. 3). Ecologists affiliated to NZ institutions are involved in a diverse range of international author collaborations with strong links between NZ authors and the USA, Canada, South America, Europe, and Australia (Fig. 3), and these have diversified since 2000. Similar patterns were described by the Ministry of Business, Innovation, and Employment (MBIE; 2018) who noted that across the NZ science sector, the rank-order of international collaborations was USA > Australia > UK > Germany > China (2014–2017). As noted above, by 2020 nearly half of all publications about NZ ecology or with a NZ-affiliated author had at least one international co-author.

Patterns of affiliation-level collaboration

Within NZ, co-author affiliation networks have become more connected over time and the number of institutions in the network has also increased (Fig. 4b vs. Fig 4c). The current ecological collaboration structure in NZ (Fig. 4) comprises core hubs (CRIs and universities), with satellites of collaboration around them. Ultimately these changes reflect shifts in who does research and where. These trends are in part explained by

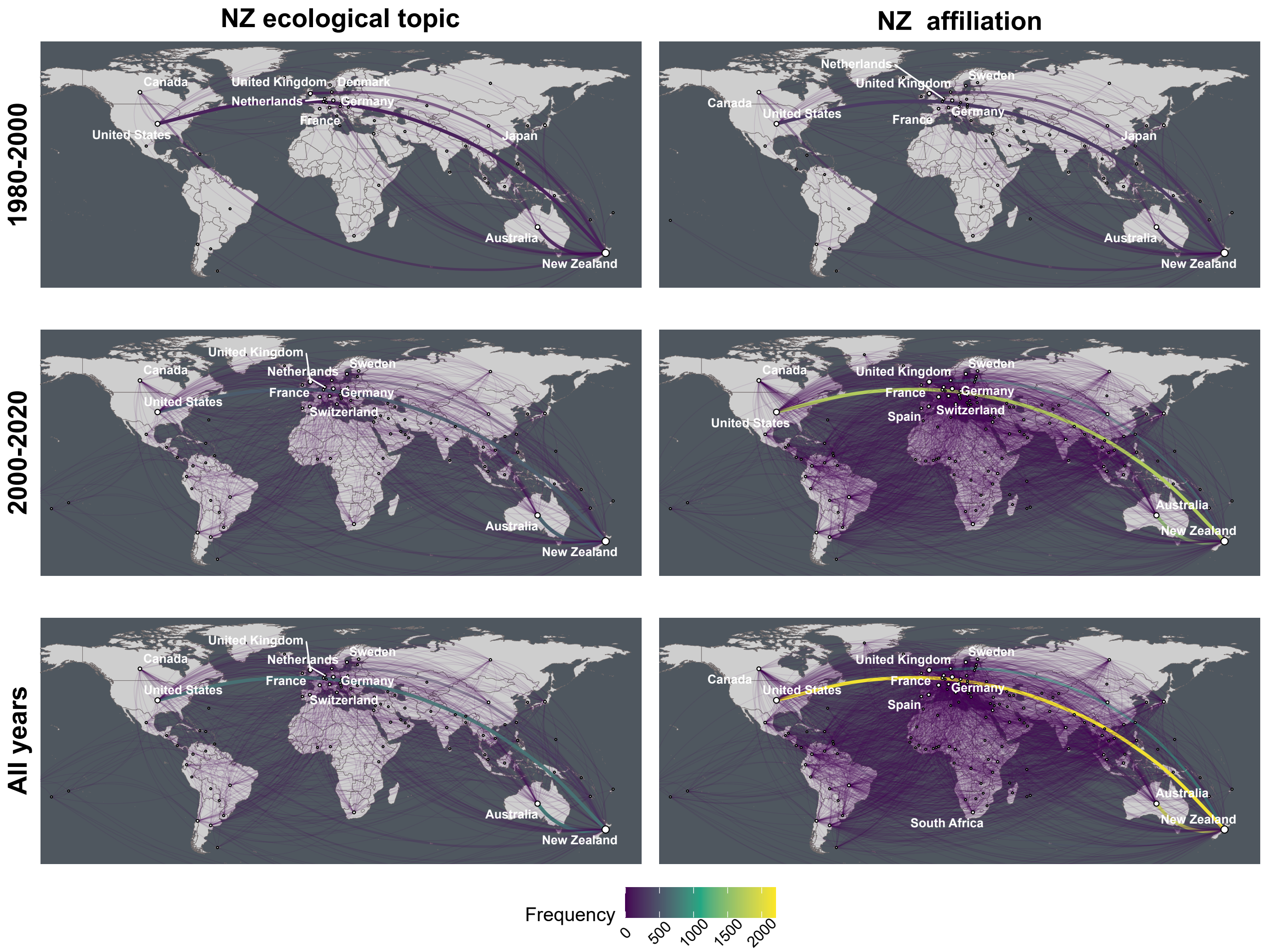

Figure 3. Geographic structure of author collaborations (since 1980) for publications focussed on NZ ecology (left column) and ecological publications with at least one author with a NZ affiliation (right column), sliced by time. Width of link is proportional to number of interactions (collaborations). Note the international collaboration network of NZ affiliated researchers intensifies more over time than that of those conducting research on NZ ecosystems. Labels denote countries in the top ten for collaborative links in each map.

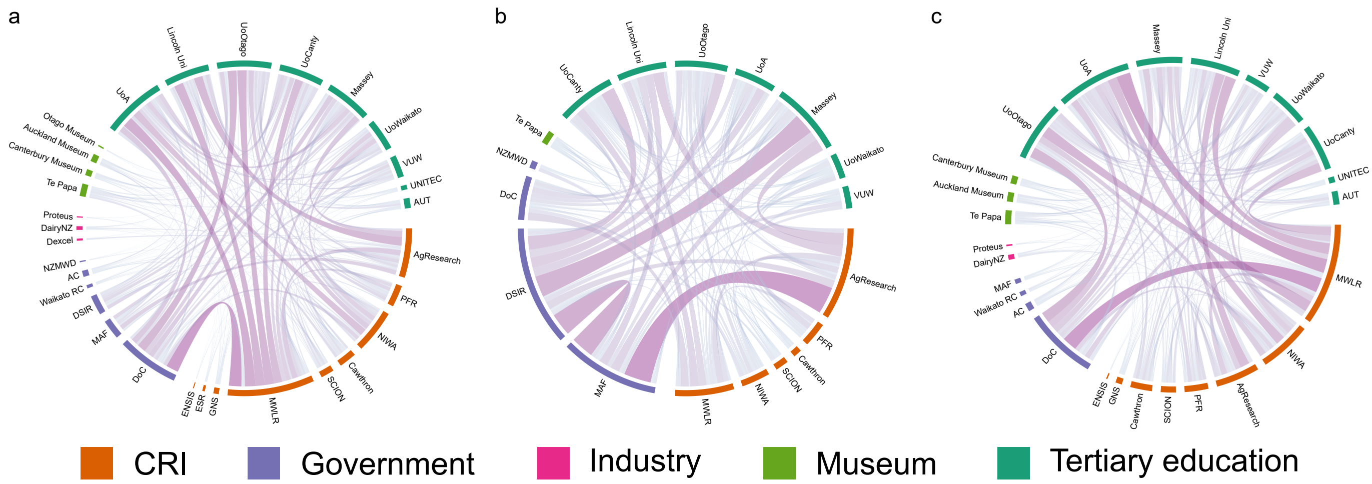

Figure 4. Collaboration across NZ institutions in the ecological literature corpus (topic and affiliation). Colours denote organisational groups (CRI, museum, government, industry, tertiary) with organisations with multiple sites collapsed to one, e.g. the various locations/offices for Manaaki Whenua Landcare Research or the National Institute of Water and Atmospheric Research (NIWA). The strength of links number is weighted by the number of co-publications. (a) all ecology, (b) 1980–2000, (c) 2000 onwards. Interactive versions of these networks are described in Appendix S3, and the abbreviations are available in the supplementary data.

both the increasing production of science over time and changes in the NZ science system that have driven larger collaborative teams and networks (e.g. NZ's National Science Challenges; see Perry & McGlone 2021). For example, in 1992 the CRIs were formed out of the Department of Scientific and Industrial Research (DSIR) and other government entities, which led to an increase in the number of institutions producing ecological science. Collaboration with the industrial (private) sector has increased, especially in agricultural areas and in recent years through initiatives such as Predator Free NZ (not evident in figure). This change reflects both funding sources and drives for industry-linked applied research. In the 1980s government agencies (especially the DSIR) produced more publications than the University sector. However, since 1992, the rate of production in universities (whether absolute or fractional) has grown much more rapidly than that of the CRIs or government.

Patterns of individual-level collaboration

Over time, the nature of the author-level collaboration structure among NZ ecologists and those publishing on NZ ecology has changed in ways that tend to mirror changes in patterns of productivity and affiliation networks. Over the period 1980–2020 there are obvious clusters of co-authors, representing thematic areas, geographic locations, and institutional affiliations. During the period 1980–2000, the collaboration network comprised a collection of small, somewhat discrete clusters (mean degree = 3.7) often within a single institution or location. However, since 2000 the clusters have coalesced and are more strongly linked (mean degree = 10.2), with a core group of collaborations spanning multiple institutions (Fig. 5).

Keyword analysis

The keywords used by authors to characterise their research provide a high-level view of the predominant topics in a body of literature (Fig. 6). The prevalence of specific keywords has shifted over time in publications both about NZ's ecosystems and by NZ ecologists. A consistent theme has been in plant taxonomy, especially in the period 1980–2000 with some decline since then. Since 2000 there has been an increase in the use of terms associated with more applied ecological topics: conservation, invasion biology, invasive species, climate change. On the other hand, there has been a decline in keywords with an agricultural focus especially in the affiliation corpora. It is interesting to consider the species mentioned as keywords. The only native genus appearing in the top keywords is *Nothofagus* (in the topic corpus, 1985–1990), with the other taxa being agricultural (e.g. *Trifolium repens*, *Lolium perenne*), silvicultural species (e.g. *Pinus radiata*) or pests (e.g. *Trichosurus vulpecula*). These keywords relate to clusters of topics, which also change over time. There are multiple reasons for the waxing and waning of the use of specific keywords. While it may represent a genuine change in a topic's prevalence, usage is also influenced by social decisions around what keywords to use and a potential dilution effect as journals specialise and the number of publications increases.

A co-occurrence network based on keywords highlights clear clusters of activity (topics). Combining the topic and affiliation corpora (Fig. 7a, visualised as a word cloud) highlights five groups: (1) agricultural (pasture) growth, (2) conservation and population dynamics, (3) NZ flora and taxonomy, (4) environmental change and human impacts in aquatic systems, and (5) conservation, climate change, and invasive species. These same clusters are evident when the topic corpus and the affiliation corpus are considered separately (Figs. 7b and 7c, respectively), albeit with some slight nuance and differences in the keywords identified.

Topic modelling via Structural Topic Models

There are broad similarities in the topics identified by the structural topic models for the topic corpus, the affiliation corpus, and the combined corpus (Appendix S5 and S6), so we focus on the combined corpus and use the covariates to

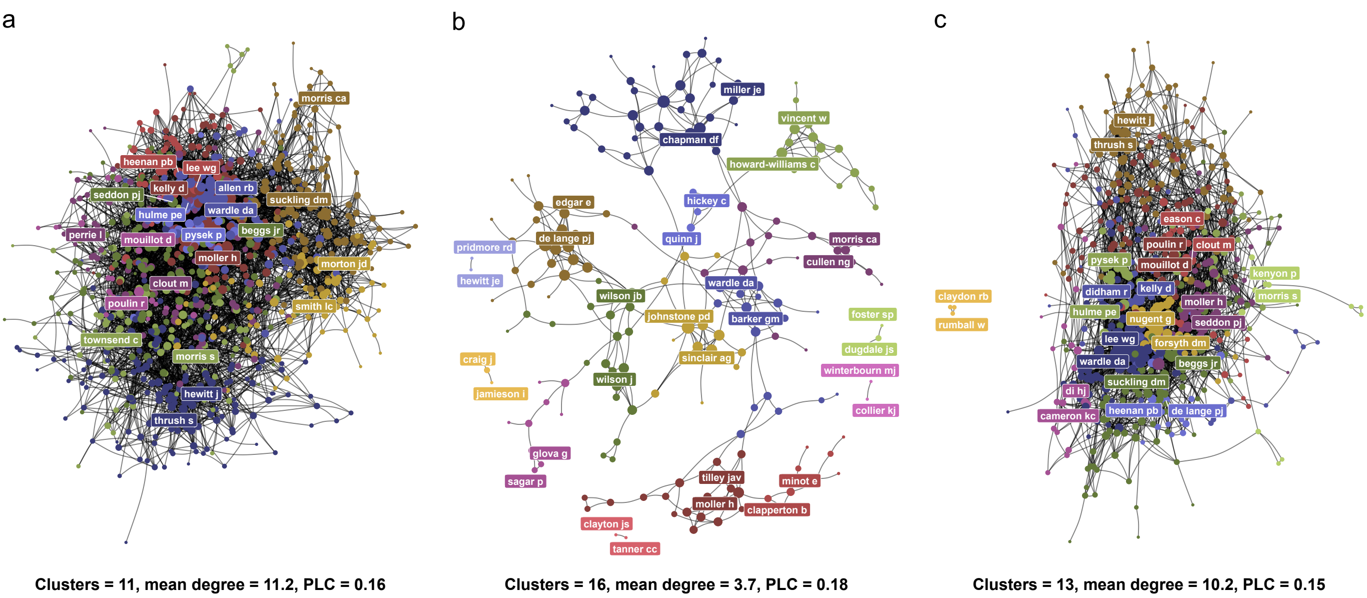

Figure 5. Co-authorship networks for all ecological records (combined-corpus) for (a) 1980–2020, (b) 1980–2000, (c) 2000–2020. Colours are the clusters identified by the Louvain algorithm, the size of the circle is the centrality of the author, and the labels are the two highest weighted (Newman-Fowler weights; Fowler 2006) authors in each cluster. Minimum number of publications to be included in any figure was 10. PLC = proportion of nodes (authors) in the largest cluster. Interactive versions of these networks are described in the Supplementary Material.

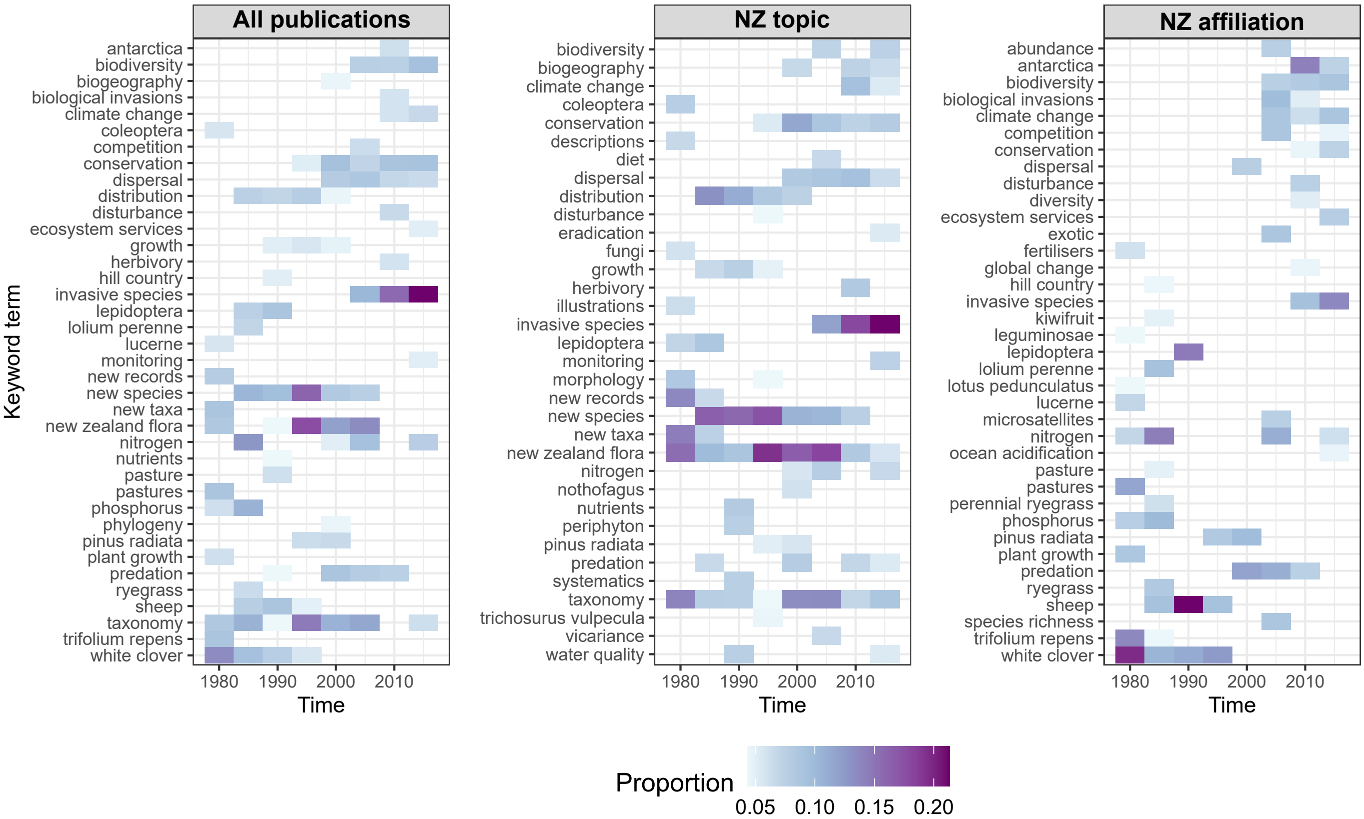

Figure 6. Prevalence of keywords (not lemmatised) over time (five-year slices) in (a) all records (combined-corpus), (b) NZ ecology (topic-corpus) and (c) NZ affiliated ecologists (affiliation-corpus). The fill is scaled to the proportion that each term accounts for among the top ten most used keywords in each five-year time slice. Because they were ubiquitous and prominent the keywords 'New Zealand' and 'Australia`' were removed.

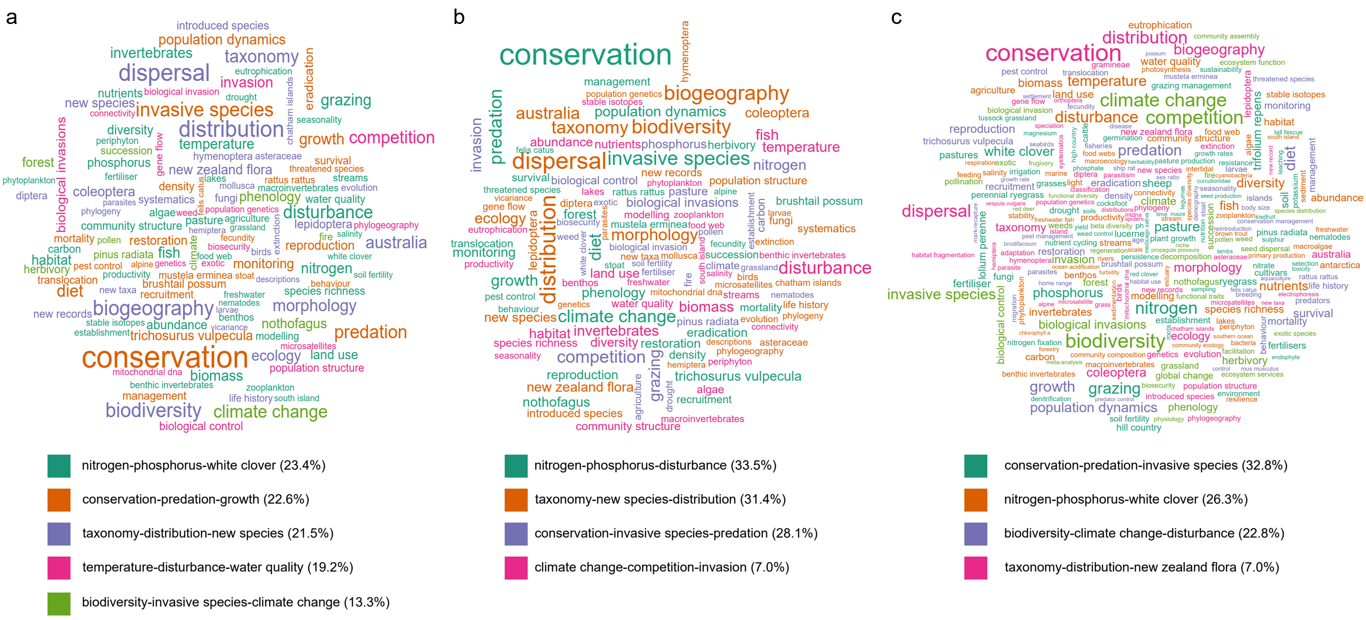

Figure 7. Word clouds showing author keywords for (a) all ecological publications (combined-corpus), (b) ecological publications addressing NZ topics (topic-corpus), and (c) ecological publications with a NZ-affiliated author (affiliation-corpus). Colours show cluster membership in a keyword co-occurrence network (clusters identified by the Louvain algorithm; Blondel et al. 2008); only keywords appearing at least 30 times are shown and clusters are not shared across corpora; % in the legends are the prevalence of each cluster. Interactive versions of the co-occurrence networks are described in the Supplementary Materials.

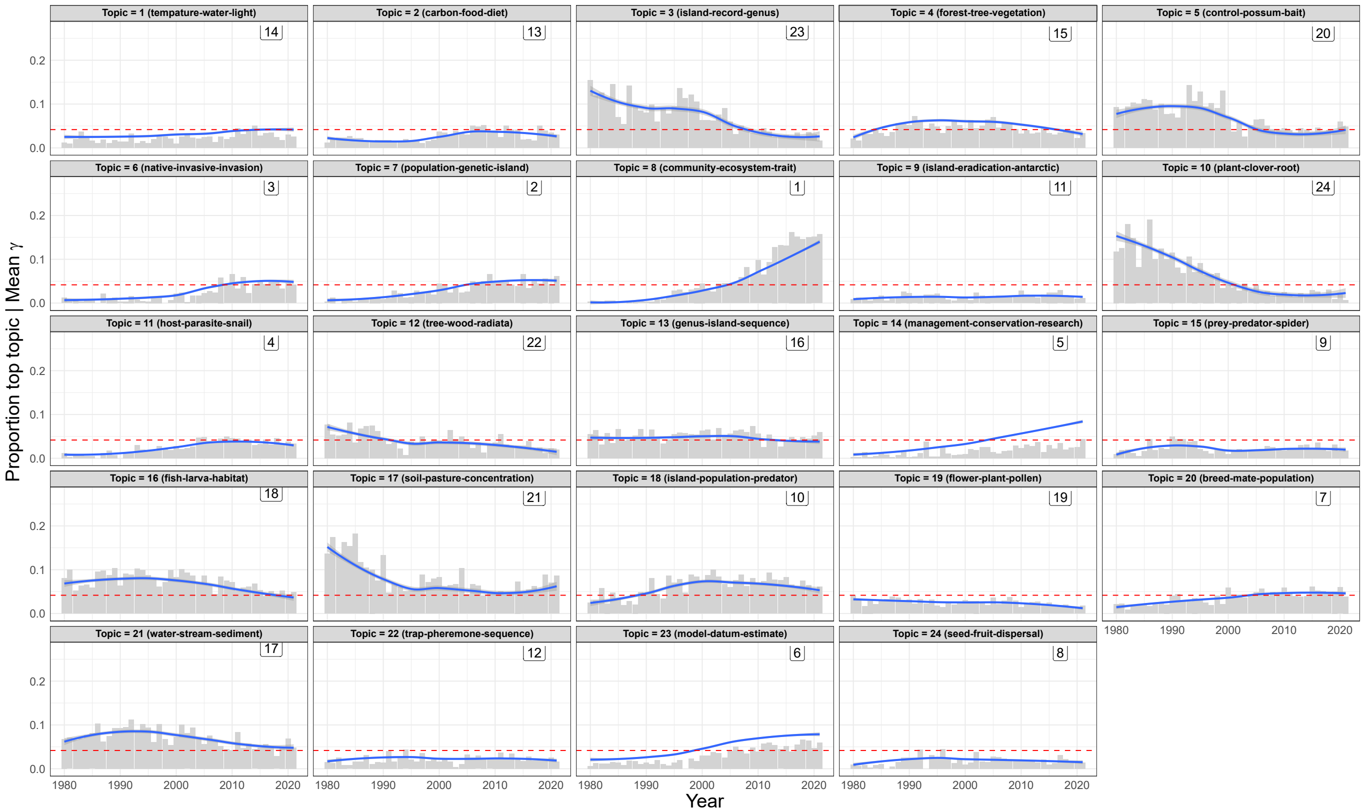

Figure 8. Changes in topic prevalence over time (1980–2020) for the entire ecology corpus with topics labelled by the top three terms in each. The bars are the proportion of publications in each year most strongly associated with topic k. The blue line is the mean g for that topic over time (higher g corresponds to more records in that topic) and the red line is the null of $1/k$ (proportion expected if the k topics were equiprobable). The numbers in the boxes show how the rank of each topic has changed since 1980, from highest increase in prevalence to largest decrease in prevalence. The actual topic numbers have no intrinsic meaning.

identify trends. There are temporal shifts in the prevalence of the k = 24 topics (Fig. 8 and Appendices S7 and S8); some have greatly increased in prevalence over time (the top three increasing topics are 8 [community-ecosystem-trait], 7 [population-genetic-island], and 3 [native-invasive-invasion]) while others have declined (the top three declining topics are 10 [plant-clover-root], 3 [island-record-genus], and 12 [tree-wood-radiata]). Those that have increased relate to subject matter surrounding community ecology, climate change, conservation management, and invasive species and eradication, while those that have declined relate to agroecological topics and, to a lesser extent, taxonomy. There is also evidence for shifts in specific foci, such as invasive mammals of concern; for example, there is a marked decline in topic 5 [control-possum-bait] after a peak in the 1990s, reflecting the shifts described in Perry & McGlone (2021). Some topics have been consistently present in the corpora, representing long-term interests and concerns for NZ ecologists (for example, water quality [topic 1], forest dynamics [4], pest control [9], and seed dispersal [24]).

Interactions between year of publication and NZ journal show the emergence of a distinctive local literature over time (Fig. 9). Topics with a significant positive interaction effect show divergence in the prevalence of the topic over time in the local and international literature. For example, topic 18 [island-population-predator] has increased overall over time but has decreased in the international literature (Fig. 9), suggesting a retreat of this topic (likewise for topics 4 [forest-tree-vegetation] and 13 [genus-island-sequence]). Other topics have a significant negative interaction effect, with differences in the rate of change of topic prevalence in the local and international literature. For example, topic 8 [community-ecosystem-trait] is the topic with the highest increase in prevalence overall and this is much higher in the international than local literature. Those topics with no significant interaction have shown similar temporal trends irrespective of publishing venue and include some such as topic 14 [management-conservation-research] that have dramatically increased over time. In summary, these patterns suggest that over time some topics have shifted to local journals, while others have shifted to the international literature.

Discussion

Publishing trends in the New Zealand biological and environmental sciences

At the broadest level, the trends seen in global science over recent decades are evident in the corpora we consider: rapid growth in production (1–5% per year, 1980–2020), increased dominance of large authorship teams, and increased inter-institution and international collaborations. In universities these trends reflect shifts in the global science system, including changing incentives and rewards structures for authors and the increasing demand by many states that universities generate revenue (Stephan 2008). At the same time, international collaboration has been facilitated by new technologies

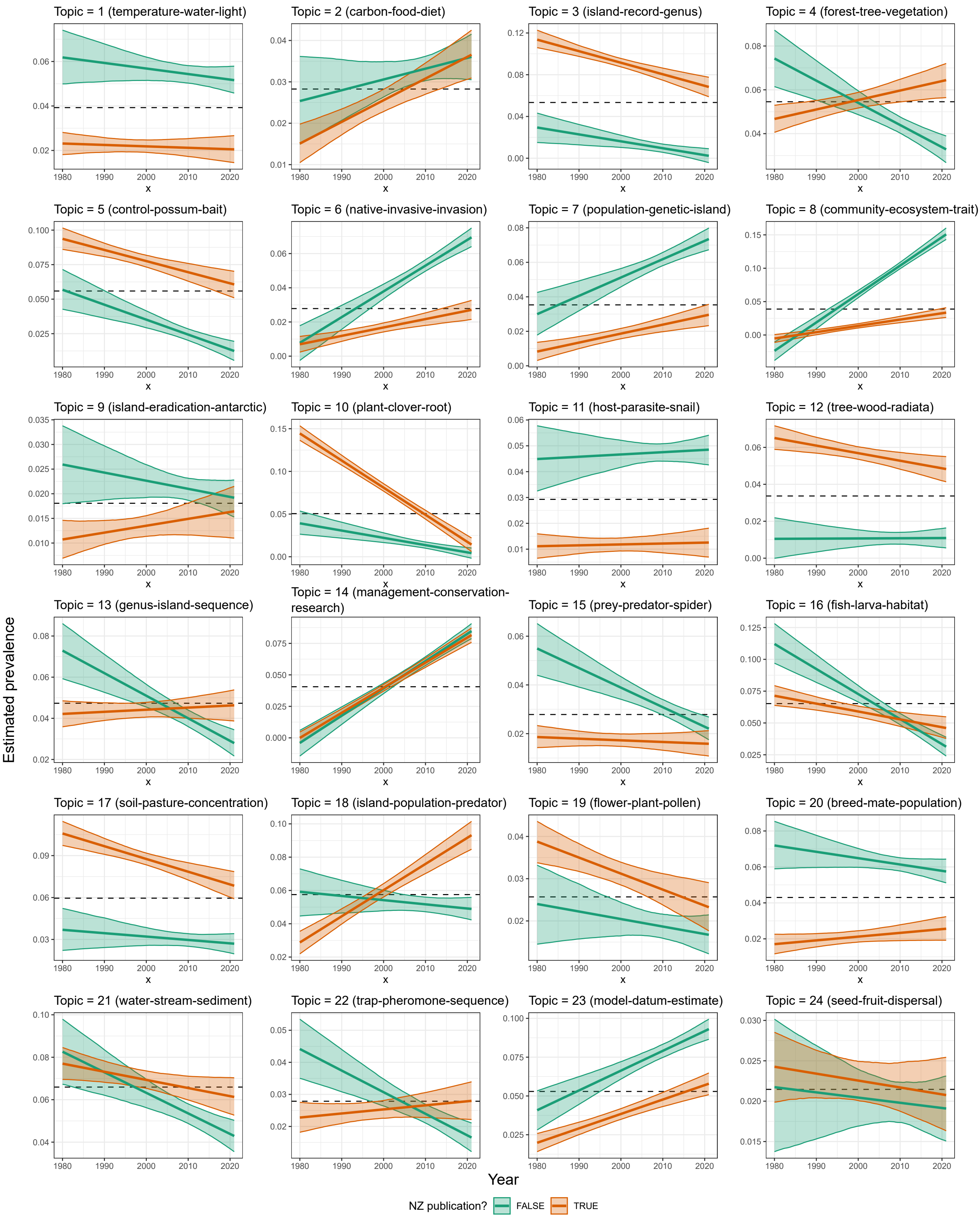

Figure 9. Predicted prevalence as a function of year of publication, whether a publication appeared in a NZ journal, and their interaction for each of the $k = 24$ topic.

(e.g. video conferencing) and, over much of the period we consider, declining international travel costs. While our primary focus is not a comparison of publishing trends across the agricultural-biological, environmental, and ecological sciences in NZ, it is noteworthy that they do not show the same trends.

Publishing trends in the New Zealand ecological sciences

The production of scientific literature has increased exponentially over recent years (Fortunato et al. 2018; Wang & Barabási 2021), and this was true of the biological sciences and environmental sciences corpora (growth rates of 3–5%). However, the body of ecological publications showed some rather different trends, in particular slower growth in publication on NZ's ecology and ecosystems and by NZ-affiliated authors publishing in ecological journals. This slower growth was particularly apparent from 1990–2000, with declining production in the early 1990s. This trend could have at least three, not mutually exclusive, reasons: (1) a genuine relative slowing in publications considering NZ ecology, (2) pressure/trends to not include country names in titles and abstracts in an effort to emphasise a publication's international nature or in response to other institutional pressure, (3) changing patterns in where ecologists publish (e.g. the growing emphasis on applied ecology may lead ecologists to publish in environmental science journals rather than ecological ones), or (4) changing emphases in the types of research conducted (e.g. from field-based research to syntheses as observed in conservation science; Ríos-Saldaña et al. 2018). A marked decline in the production of ecological publications (1988–1992) coincides with the lead-up to and formation of the CRIs in 1992 which, because of widespread redundancies in government-funded science institutes, resulted in an abrupt fall in the overall science workforce by c. 30% (Edmeades 2004). The NZ science reforms led to a rapid shift of government funding from government-owned organisations to the universities (and to a lesser extent to private providers). Because of the more international, less local focus of the universities, and the very much broader range of science topics researched there, this inevitably negatively impacted local ecological research. Since the 2000s there has been rapid growth in publication rates in the universities, which can largely be attributed to the increased provision of government funding; this has been accelerated by NZ's Performance-based Research Fund (PBRF, Smart 2009) which has provided strong incentives for university researchers to increase their output (or at least the number of papers they appear on). As well, there has been growth in the number of PhD students and pressure on them to publish (Yeung 2019).

Collaboration networks in ecology in New Zealand

There are two clear trends in the collaboration networks formed by NZ-based ecologists and in ecologists publishing on NZ ecology. First, there is a trend towards increasing international collaboration and second, there is increasing cross-sector collaboration especially with the business sector (i.e. beyond CRIs, museums, and universities). According to the MBIE (2018), worldwide the average rate of international collaboration (based on co-authorships) is 25%, but by 2020 nearly half of the publications we considered (whether NZ topic or NZ-affiliated author) had at least one international co-author. This figure is close to MBIE's estimate of 56% of all publications across all sciences in NZ having an international collaboration (vs. 39% in 2010; MBIE 2021). Over the period 2010–2020 there was a 70% nominal increase in research and development expenditure in NZ, largely driven by the business sector who now account for 60% of such funding (MBIE 2021). However, there is very limited direct collaboration between ecologists and industry (Fig. 4b). Another important trend is the increasing dominance of universities in terms of producing publications. By 2020 universities accounted for nearly four-times as many publications as did the CRIs or government sectors. Again, this change results from massive shifts in funding away from government-owned laboratories (especially the PBRF; Smart 2009) and from pressures to publish, especially among doctoral students.

Changes in thematic emphases in ecology in New Zealand

Over the last few decades, several studies have documented apparent shifts in the dominant themes in the ecological literature. For example, Anderson et al. (2021) used *n*-grams to document changes in ecology over the period 1930–2020 and describe shifts from local to macro-scale studies and the use of more and more complex quantitative methods (e.g. species distribution models); likewise, on the basis of analysis of keywords in the most cited papers, Zettlemoyer (2023) described similar shifts and a growing emphasis on the applied issues surrounding environmental change and human response to it. To some extent these patterns are mirrored in the NZ ecological literature, although there are significant differences between research published about NZ and that published by NZ-affiliated ecologists. Over the 40-year period we consider, there have been shifts towards more applied topics (e.g. invasive species and climate change) and a move to more model-based and meta-analytic ecological studies. These trends are strong in the literature published by NZ-affiliated ecologists, reflecting the more international nature of the material that corpus includes. The shifts in the studies on NZ are similar but also reflect local concerns such as control of invasive mammals. Thus, the broad NZ ecological literature (by NZ-affiliated scholars and about NZ) reflects broad global trends with some local flavour.

It is also interesting to speculate about what topics will emerge in the future. One obvious current omission is a discrete topic surrounding Mātauranga Māori, especially given the increased requirements over recent years for engagement. In our corpus just 174 of 19100 (0.9%) records include either of the terms 'Mā(a)tauranga' or 'Mā(a)ori' in their abstracts, although their prevalence has increased since 2010 (Appendix S9). Furthermore, the subject matter of these 174 papers is diverse and is far from a coherent subfield focussed on Mātauranga. New techniques are certain to rise to the fore (e.g. AI, eDNA); this could drive differentiation in areas such as topic 23 (model-estimate-datum). Conversely other topics may continue to decline or retreat into the local literature. What shifts are occurring (aside from those resulting from technology change) seem mainly related to the nature of perceived environmental threats (for example, incursions of new pathogens such as myrtle rust (*Austropuccinia psidii*) or new invasive organisms, such as freshwater gold clam (*Corbicula fluminea*), which have economic as well as ecological impacts. Because of the competitive allocation of mostly short-term funding to individual research groups, strong, long-term programmes have become almost impossible to sustain. NZ, for instance, now lacks any Long-Term Ecological Research (LTER) sites — the defunding of government science resulted in the disestablishment of those which were supported by the DSIR and NZ Forest Service. Thus, there is a lack of the types of research infrastructure, funding mechanisms, and collaboration opportunities supported in the USA by the LTER network and National Ecological Observatory Network programs (Jones et al. 2021), and in Australia by the Terrestrial Earth Research Network (Cleverly et al. 2019). Short-termism currently prevails.

What do these trends mean for New Zealand's local ecological journals?

Why do scholars publish? What is the value proposition for selecting a journal? These questions are central to understanding the aggregate trends we present. Googling "why publish research?" returns hits that emphasise its social capital (to the author). As Bourdieu (1988) articulates in *Homo academicus*, the rewards of scholarship are entangled in a complex milieu of power, agency, and knowledge. If this is the case, it is no surprise that in a peripheral country such as NZ we see a growing divide between the local and international literature (Fig. 9). We also see a NZ ecological science more embedded than ever in international collaborative networks (Fig. 3). Perhaps, of itself, a distinct local alongside an international literature is not a problem. In other branches of scholarship disciplines have multiple literatures, serving different purposes (Hicks 2005). Further, it could be argued that this divide is irrelevant given that the digital world facilitates finding research of interest wherever it is published. However, socio-economic theory contests this argument. First, the Matthew effect (Merton 1968) "For to everyone who has will more be given, and he will have abundance; but from him who has not, even what he has will be taken away. Matthew 25:29", is based on the observation that many factors besides merit determine scientific visibility and hence citation. Empirical evidence shows that under a deluge of information, positive feedback dynamics ensure that well-cited papers continue to be more cited (Nielsen & Andersen 2021). Scholars in peripheral nations (in the quoted case Argentina, Brazil, and Norway) disproportionately cite research from central countries rather than research from their own, but this may not be reciprocated, suggesting "different inward and outward markets for their scientific information" (Rabkin & Inhaber 1979, p. 272). Where English is not a country's primary language such effects may be even more pronounced.

A dominant trend across NZ science over the last 50 years has been towards ever stronger links to the international science community. This trend is two-way. NZ's biota and ecosystems offer an ideal testbed for answering some fundamental (e.g. mast seeding) and applied (e.g. effects of invasive mammals) ecological questions. Looking outward from NZ, local scientific prestige now is largely dependent on international recognition; increasingly scientific institutions are staffed by expatriates from the cosmopolitan science powerhouses, who naturally enough favour publication in the international journals where they began their careers. The question "why publish in a local journal?" thus has become critical.

In our view, publication in a local journal provides contextually critical knowledge. Given that the pressing environmental challenges we face are geographically situated, this is important. NZ's local ecological journals are well-placed to deliver research to target audiences such as the managers of endemic species or local ecosystems and can also publish studies that show how theory applies in a NZ context that may be less relevant internationally. Local journals are also potentially more responsive to local context; for example, an open access copyright position was adopted by the *New Zealand Journal of Ecology* (NZJE) in an effort to more closely align with Te Tiriti o Waitangi (Etherington et al., 2022). Such issues may not be a concern of international journals. Local journals also have important educational and other benefits depending on the discipline that they publish. However, studies beyond NZ suggest that the internationalisation of the literature has had negative local effects. There are undoubtedly strong pressures to make a given study internationally relevant, pressures most acutely felt by early-career scientists whose advancement depends on recognition by impartial agencies and selection committees. Local journals are therefore sometimes perceived as a last resort (Ofori-Adjei et al. 2006). They therefore tend to lose out on high quality material and end up publishing an irrelevant middle ground (Kang 2009). It does not help that local science is then published in international journals that may be inaccessible, for financial or other reasons, to local readers (Neff 2018).

The effects of such pressures are evident in our analyses showing a retreat of some locally important topics (e.g. forest dynamics, plant taxonomy, some aspects of predator control; Fig. 9) to local journals. These pressures change things as fundamental as language: for example, what once was "lowland podocarp-hardwood forest" becomes "temperate rainforest", "West Coast" becomes "high rainfall temperate zone" and "New Zealand" becomes "southern temperate zone". It is as though to mention the name of the country is to condemn the paper to local insignificance. Vessuri et al. (2014, p. 649) describe shifts in Latin American science under institutional demands to internationalise (further exacerbated in their context by language barriers). They ask the rather gloomy question: "Is it possible that, as result of this regime, scientists from the 'periphery' actually contribute more to problems affecting mostly rich countries (a kind of foreign aid in reverse) rather than their own?".

Sustaining resilient (local) ecological publishing in New Zealand

The purpose of our analyses, beyond the inherent interest in trends in science publishing, is to contribute to a discussion about building a resilient NZ ecological science. At one level, there is an altruism to our argument; sacrificing prestige can benefit local ecosystems. We strongly believe this to be true. Local debate, largely moderated by local editors and reviewers, and given the space to address questions of high local relevance, should improve ecological outcomes for NZ. The question then is how to lower the altruistic cost (or make sure that NZ journals are first resorts for some research). The relationship between material production and economic structures in scientific publishing are beyond our scope here (but are important, as discussed by Neff 2020). NZ will always be somewhat peripheral globally, if just by virtue of the size of the research population, and other studies have demonstrated the inherent challenges to local journals in this context (Ofori-Adjei et al. 2006). Nevertheless, we could start by surveying the ecological science publishing landscape in NZ (building on the arguments made in Perry & McGlone 2021 based on analysis of a much smaller body of literature). There are 4–5 journals publishing, to a lesser or greater extent, ecological science in NZ. Do we need this many? Do we suffer from a dilution effect? The inherent problem of specialised journals in a local context of low publication rates is described by Perry & McGlone (2021, p. 11): "Local journals suffer from four disadvantages. They have low prestige; they have low submission rates; they have a small pool of potential contributors; and they have the double handicap of a restricted topic area plus a restricted location".

Editors have few levers to pull in this regard. For example, the NZJE rarely publishes non-terrestrial papers. This is an accident of history not a decision by the journal editors.

Could a revitalisation of the local journals, if not to their pre-1992 glory days but to one in which they are the publication of choice for locally focused research, ever be viable? We do not have a definitive answer, but we suspect that if as a community we do not engage in this question, a choice to publish in local journals will continue to be regarded as one made largely on the perceived novelty, quality, and relevance of the work, not appropriateness of the venue and audience. This is a different question from the long-term viability of these journals. In the case of the NZJE, for example, there seems to be a clear niche, a loyal club of authors, and it is open access (Perry & McGlone 2021; Etherington et al. 2022); these do not, however, of themselves address the potential disincentives to publishing in a local journal. Even if a core subset of local journals were centrally funded and treated as a public good there would still need to be adequate incentives to publish in them. However, this is not primarily a call to individual scientists; without a change in attitudes at the top of our scientific organisations the trends we have outlined here will continue. If so, we will end up with an increasingly fractionated publishing landscape for ecological science in NZ that runs counter to the cross-ecosystem research required to meet the challenges faced by our ecosystems and biota.

Summary

The longitudinal analysis of a large body of literature can provide insights into how knowledge production in a discipline has changed over time due to shifting scholarly interests and the science structures in which researchers are embedded. Our analysis of 40 years of publications by NZ ecologists and about NZ ecological systems suggests trends like those in ecology as a whole, but with some local flavour. There has been a shift towards applied ecological questions (e.g. invasion and climate change) and the adoption of macroecological and modelling methods (e.g. species distribution models); however, some themes have been persistent, including a concern with the management of vertebrate pests. There have also been shifts in the funding and structural landscape for NZ science over the last 40 years that are, to some extent, reflected in where science is produced and its focus. The apparent division between the topics published in local and international journals is of particular interest. We believe serious reflection on the NZ ecological publishing landscape is overdue.

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Author contributions: GP and FL designed the study; GP performed the data analysis; GP, FL, and MM all contributed substantially to writing the manuscript.

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Supplementary material

Additional supporting information may be found in the online version of this article:

Appendix S1. R packages used in the analyses.

Appendix S2. Custom stopwords.

Appendix 3. Interactive network figures.

Appendix S4. Number of records associated with universities, CRIs, and central government in NZ.

Appendix S5. Cumulative plots of (A) number of unique journals published in over time, (B) number of unique author affiliations, (C) number of unique countries, and (D) number of unique authors.

Appendix S6. Summary of the topics from the k = 24 structural topic models with year, NZ journal, and their covariates for (A) publications with NZ-affiliated authors (B) publications on a NZ topic, and (C) all publications (A and B combined).

Appendix S7. Labels for 1–12 of the 24 topics identified by the STM.

Appendix S8. Labels for 13–24 of the 24 topics identified by the STM.

Appendix S9. Number of abstracts with either of the terms Māori or mātauranga appearing in them over time.

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