Historical collections as baseline for assessing the extent of the pollinator crisis

I. Bartomeus1, J. Stavert2, D. Ward2,3, O. Aguado4

Historical collections or museum collections?

*Affiliations:* 1 Estación Biológica de Doñana (EBD-CSIC), Avda. Américo Vespucio 26, Isla de la Cartuja, E-41092 Sevilla, Spain  
2 Centre for Biodiversity and Biosecurity, School of Biological Sciences, The University of Auckland, Auckland, New Zealand 3 Landcare Research, Auckland, New Zealand 4 Andrena Soluciones  
\*Correspondence: [nacho.bartomeus@gmail.com](mailto:nacho.bartomeus@gmail.com)

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# Abstract

There is increasing concern about the decline of pollinators worldwide. However, despite reports that pollinator declines are widespread, data are scarce and often geographically and taxonomically biased. These biases limit robust inference about any potential “pollinator crisis”. Analysis of historical time series data is the most direct approach for assessing species declines, but long term monitoring programs targeting pollinators are limited. However, non-structured and often opportunistic historical data collections are more frequently available. In many instances, these data provide the only source of historical information serving as a baseline for identifying pollinator declines. Specimens historically collected and preserved in museums can provide information on where and when species were collected, in addition to other ecological information (e.g., historical species interactions and morphological traits). Here, we provide a synthesis of how researchers have used museum specimens to compare historical occurrences with current patterns to identify long-term changes in biodiversity, species abundances, body size and pollination services. Despite recent advances, we show that information on the status and trends of most pollinators is absent. Furthermore, we identify lack of collection record data digitization as a key bottleneck, impeding progress in this field. We highlight opportunities and limitations to progress assessment of pollinator declines globally. Finally, we demonstrate different approaches to analysing museum collection data using two contrasting case studies from distinct geographical regions (New Zealand and Spain) for which long-term pollinator declines have never been assessed. We show that for both regions, winner and loser species emerge despite non-significant changes in species richness over time. There is immense potential for museum specimens to play a central role in assessing the extent of the global pollination crisis, but to progress this field data must be made feely accessible to researchers.

# Introduction

Animal pollinators are a critical component of both natural and agricultural ecosystems worldwide, given their role in plant reproduction [1] and food security [2]. As with many other taxa, pollinators are vulnerable to a range of anthropogenic disturbances, which can cause local and regional population declines or even extinctions. The vulnerability of pollinators was identified several decades ago, and was popularized in 1996 by the influential book “the forgotten pollinators” [**???**]. However, early accounts were somewhat anecdotal, given the lack of data on pollinator populations at that time. These initial claims triggered the first efforts to assess the problem, including the formation of a US National Academy of Science (NAS) panel in 2006, which was commissioned to assess the extent of pollinator declines. The NAS report concluded that “For most pollinator species […] the paucity of long-term population data and the incomplete knowledge of even basic taxonomy and ecology make definitive assessment of status exceedingly difficult” [3]. Since then, studies on pollinator responses to various global change drivers have multiplied rapidly. Researchers have now developed strong consensus that disturbances such as habitat destruction, land-use intensification, chemical exposure, exotic species and climate change are causing pollinator declines, and often act synergistically [4,5]. Yet, the current status and population trends of most pollinator species worldwide remain unknown. For example, a recent IUCN report concluded that even for Europe’s comparatively well-studied bee fauna, greater than 55% of bee species fell into the “Data Deficient” category [6]. For countries outside of Europe and the US, data on pollinator populations is almost non-existent.

One of the main barriers to identifying pollinator population trends is that pollinators are incredibly taxonomically diverse and include bees, flies, butterflies, beetles, birds, bats and even lizards [7]. Additionally, many pollinators are highly mobile, short-lived and small, which makes monitoring their populations difficult. Bees are generally regarded as the most important pollinator group due to their abundance, pollination efficiency and widespread distribution [8]. However, bees are diverse, with more than 20,000 species currently described worldwide [9], and often require expert taxonomists for identification. Furthermore, the uneven distribution of researchers [10] has resulted in geographical biases in bee decline research, as well as taxonomic biases toward species that are easier to identify, such as bumblebees [9,11].

One solution to overcoming these barriers has been to use space-for-time substitutions, where researchers compare pollinator populations across environmental gradients. Despite critiques on the robustness of this approach [12,13], these studies currently provide the most extensive source of data on pollinator populations. For example, researchers have recently estimated bee richness declines for every country in Europe using predictions from models of pollination associations with different land-use types [14]. A second important method is the use of data collected from pollinator monitoring programs, which are often driven by citizen scientists. This approach was inspired by successful butterfly monitoring programs [15] and is currently being extended to other pollinator taxa. However, these programs require significant time to generate long-term datasets and cannot be used to assess historic pollinator populations. Finally, the most practical approach for assessing long-term historical pollinator population trends is to use the historical information on species occurrences, which is archived in museum collections [e.g., **???**].

In this review, we first assess current evidence for pollinator richness declines and present a road map outlining a strategy for using museum collection data to fill current knowledge gaps. We highlight the major technical difficulties involved in using museum collection data and demonstrate several approaches for analysing different types of museum collection data to assess long-term trends in pollinator populations. Finally, we highlight the need to move beyond simple biological diversity descriptors and unleash the power of historical data to assess changes in species interactions, ecosystem functioning and evolutionary changes through time.

# Current evidence on pollinator declines

At a global scale, current evidence of pollinator declines is highly limited with most data restricted to the US and Europe. It is unsurprising that studies on pollinator declines are biased towards developed western countries, which have also been subject to extensive anthropogenic disturbance. For example, in the UK and the Netherlands, a citizen science based study using both observations and museum collection data detected strong richness declines for bees, hoverflies and flowering plants [16]. However, it is important to note that even for these two countries, local estimates of pollinator richness are biased toward large cities and regions dominated by agriculture, and thus data is lacking for natural areas. Further exploration of this dataset revealed that for declining pollinator taxa, the trend has attenuated in recent decades [17].

In the Netherlands, museum data have revealed simultaneous plant and pollinator declines [18]. Specifically, bee species with the strongest host plant preferences (i.e., specialists) displayed the strongest declines and thus, were most threatened with extinction. Although studies of local pollinator communities often detect richness declines, regional richness may remain relatively stable. For example, regional estimates for species richness changes in the eastern US show moderate declines [19] and very few regional extinctions [20]. This is a pattern also detected in the UK [21]. However, the reginal US findings above are in stark contrast with the widespread local extinctions reported by Burkle [22], who compared historical observations of bee species’ occurrences in a large forested ecosystem with remaining forest remnants. It is important to note that Burkle [22] focused on habitat remnants and did not take into account opportunistic bee species that use novel land-use types ([23]). In any case, there is strong concordance between local extinctions and regional declines [24], suggesting that local extinctions are indicators of regional population declines.

As with bees, studies on species richness changes for other pollinator taxa are both scarce and geographically restricted. Generally speaking, reported declines for bumblebees are the most severe of all pollinator taxa. For example, declines of up to 18% in local bumblebee richness have been reported for Belgium and the Netherlands [17]. In other parts of Europe, local richness declines range from 5% in Great Britain [17] to 42% in Denmark [25]. In the USA, reported bumble decline are also severe with estimates ranging between 25% [26] and 30% [19].

For butterflies, the only evidence of richness declines comes from Europe. For example, butterfly species richness has declined substantially in the Netherlands and Belgium since the 1950’s, although declines in Great Britain have been less severe [17]. In Belgium, another study [27] found that richness declines have been severe (approximately 30%), although this study assessed richness changes over a longer time period (early 1900’s to 2000) compared to Carvalheiro [17]. In parts of Germany, declines in local butterfly richness of up to 70% have been reported [28].

There are very few studies on hoverfly species richness changes, those of which are restricted to Europe. In Belgium, Great Britain and the Netherlands, hoverfly richness changes have been modest [17]. In the Netherlands, moderate increases in hoverfly species richness have been shown, whereas in Great Britain no significant directional changes were detected [16]. Furthermore, directionality (richness increases or decreases) varies depending on the time period assessed. For example, hoverfly richness decreased in Belgium by approximately 6% from 1950-69 to 1970-80, but increased by approximately 10% between 1970-89 and 1990-2009 [17].

Outside of Europe and the US and for non-insect taxa, there are no studies on pollinator declines using historical records. In Figure 1, we show a comparison of bee species richness per area (a), bee species richness changes (b), syrphid species richness changes (c) and butterfly species richness changes (d) to highlight the little coverage that we have globally. See raw data at Sup Mat 1. For other parts of the world, there are only species-specific examples of historical losses (e.g., Bombus dalbhomi; [29]) [South Africa: **???**, maybe with plants… . However, Peter Keil flies? Moths? Butterflies!]()

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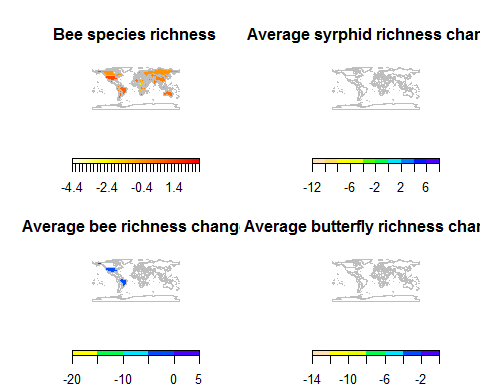


Figure 1: Global map showing a) bee species richness per area (Data from www.discoverlife.org) calculated as the residuals of the log-log regression between bee species richness and country size, which accounts for the species-area relationship; Warmer colours indicate higher bee diversity; Note that some African countries may have incomplete listed faunas and that Alaska is included with US values. (b) Syrphid (c) bee and butterfly (d) richness percent change in the last century. Warmer colours indicate steeper declines. Countries without data are coloured in white.

# Using historical museum specimen records to fill knowledge gaps

As shown in Figure 1, specific estimates are lacking for countries worldwide and use of historical museum collection data may be the most effective tool for filling those gaps.

The core aim of museums is to conserve and curate collections. Thus, they serve as a precious repository for specimens, and at the same time, often ensure higher quality taxonomic identification. Yet, the major bottleneck for researchers wanting to use these data is the lack of digitization. Digitizing old collection specimens is not a trivial task and requires expertise to (i) ensure proper taxonomic identification [30–32], (ii) geo-locate the coordinates of collection events [**???** and software] and (iii) store the data in a properly curated database [33]. Undertaking this process for tens or hundreds of thousands of museum collection specimens can be a daunting task and requires specialized personnel. While some tasks can only be undertaken by people with specialist skills (e.g., taxonomists), new technologies and citizen science can speed up the collection digitization process. High resolution photos of specimens and associated labels can be uploaded to the internet, where the task of image transcription can be distributed across hundreds or thousands of volunteers (e.g., <https://www.zooniverse.org/>). In addition, new algorithms have been created that allow location geo-referencing based on vernacular names [**???** geonames, geoparser and opencage]. However, achieving this requires adequate funding [34].

Where digitization has been completed, the data provide a rich source of information, allowing assessment of the current status and long-term trends in pollinator populations [18,19,35]. This is despite the fact that museum collections often have a number of biases, including unknown sampling effort, personal interests of collectors and the curatorial techniques used. For example, collectors tend to target rare or unusual over common taxa, discard damaged individuals or only accession a certain number of individuals. In addition, collections are often made opportunistically, leading to a spatial bias where difficult to access areas are under-sampled or conversely, where samples are biased towards easily accessed locations (e.g., towns/cities and/or along roadsides). Furthermore, this approach can only determine where species are present and not where they are absent. However, given adequate sample sizes and appropriate statistical analyses, most of these biases can be accounted for [19,36,37].

# The way forward: Prioritizing the low hanging fruit.

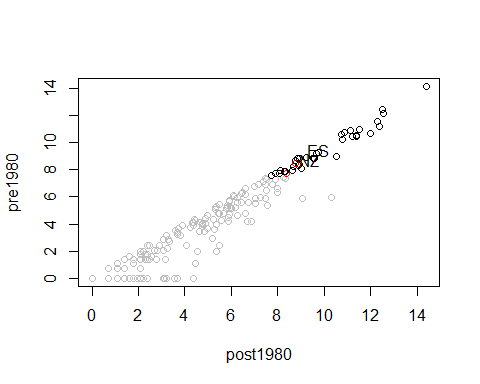
As we have shown, there is a paucity of countries for which historical data is available (Figure 1), and hence can be used as baseline for assessing pollinator population declines. While ideally one would aim to digitize all museum collection records, this is unlikely in the near future, mainly due to funding constraints. Here we show how researchers can optimize their use of museum collection data to assess long-term pollinator population changes.

GBIF (<https://www.gbif.org/>) is a central repository for global species occurrence data. Much of these data come from museums, private collections and government research institutes, but it integrates several other sources. In combination with the popular statistical language R [38], GBIF can be directly queried into your computer [39] and data availability checked for your region of interest. In Figure 2 we show the number of modern and historic bee records currently available for different countries. While values are high on both axes for countries such as the UK and the US so that data can potentially be analysed without further data collection effort, most countries fall short in one or both axes. Hence, for countries with high numbers of recent records, researchers should prioritize the digitalization of old material before embarking on data analyses (e.g. Switcherland,… ). In contrast, for countries with large numbers of historic records, re-surveys are required before analysis [40]. Interestingly, we show that greater than 100 check countries have less than 1,000 records, making them poor candidates for analysing long-term pollinator population trends. However, countries like X or X… It is also important to note that historical records are not always vouchered in local museums, but many European and US museums contain large collections of pollinators collected elsewhere. Aside from bees, similar exploratory analysis can easily be done for other taxa.

## country post1980 pre1980 percent\_post1980 percent\_pre1980 log\_pre1980  
## 130 LK 1924 208 0.9024390 0.09756098 5.337538  
## 178 PL 8581 351 0.9607031 0.03929691 5.860786  
## 43 CH 30220 373 0.9878077 0.01219233 5.921578  
## 80 GF 2997 540 0.8473282 0.15267176 6.291569  
## 164 NI 1859 667 0.7359462 0.26405384 6.502790  
## 63 EC 2945 724 0.8026710 0.19732897 6.584791  
## 237 VE 2418 993 0.7088830 0.29111697 6.900731  
## 132 LS 1831 1415 0.5640789 0.43592113 7.254885  
## 248 ZW 2750 1449 0.6549178 0.34508216 7.278629  
## 49 CO 4238 1574 0.7291810 0.27081900 7.361375  
## 172 PA 3875 1617 0.7055717 0.29442826 7.388328  
## log\_post1980  
## 130 7.562162  
## 178 9.057306  
## 43 10.316259  
## 80 8.005367  
## 164 7.527794  
## 63 7.987864  
## 237 7.790696  
## 132 7.512618  
## 248 7.919356  
## 49 8.351847  
## 172 8.262301

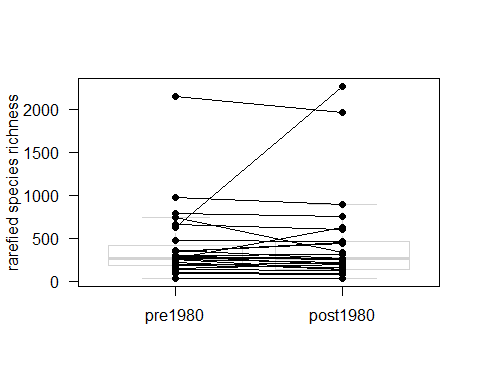
## [1] 36

## country post1980 pre1980 percent\_post1980 percent\_pre1980 log\_pre1980  
## 170 NZ 4304 2183 0.6634808 0.3365192 7.688455  
## 68 ES 6259 4659 0.5732735 0.4267265 8.446556  
## log\_post1980  
## 170 8.367300  
## 68 8.741776



## countries pre1980 post1980 n  
## 1 MA 81.36328 139.94126 148  
## 2 NZ 33.18746 33.34269 2143  
## 3 GR 121.43120 99.53617 284  
## 4 IT 260.19462 268.00948 1024  
## 5 FR 289.92343 269.49653 896  
## 6 MG 17.70772 14.62303 25

##   
## Paired t-test  
##   
## data: data2$pre1980 and data2$post1980  
## t = -0.49413, df = 27, p-value = 0.6252  
## alternative hypothesis: true difference in means is not equal to 0  
## 95 percent confidence interval:  
## -163.22291 99.86497  
## sample estimates:  
## mean of the differences   
## -31.67897



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## 214 codes from the map weren't represented in your data

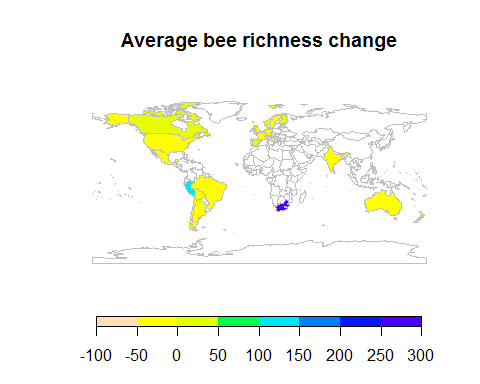


Figure 2. The number of bee occurrences before 1980 and after 1980 in GBIF. The upper right quadrat contains well covered countries and the upper left quadrat contains countries that resurveys of old sites. The lower right quadrat contains countries that require museum record digitization and the lower left quadrat contains countries with very little available data. We highlight a few representative examples. b) boxplot showing rarefied number of species collected before and after 1980. c) same data plotted in a map. This data is likely to contain strong undetected biases, but indicates little change…

Once museum collection datasets are made available, researchers must identify any potential biases in the data. We explore this process with two contrasting dataset examples (Spain and New Zealand). In the Spanish dataset, most of the data comes from a few specific locations and was collected by the same team of people. In this case, we contacted the original collectors to define their sampling protocols. We then resurveyed the same sites (20 years after the original surveys) using the same protocols. In contrast, the New Zealand dataset includes a wide suite of collectors and collection locations but shows no obvious biases in geographical and taxonomic coverage through time. For these case studies, we provide annotated R scripts for analysis of different dataset types (e.g., for Spain and New Zealand, as described above). These different analytical approaches allow us to reveal long-term trends in pollinator populations for regions with contrasting sampling histories. We hope this resource will encourage researchers to analyse data for regions where there is current information on pollinator declines is lacking.

# Case study one: Spain

Spain provides an interesting study system because its natural habitats have been transformed extensively by humans over a long time period, but land-use is not as intensive compared with many other European countries. In addition, Spain is a bee diversity hotspot (Figure 1) and maintains a relatively heterogeneous landscape. Spain has already digitalized a large amount of pollinator occurrence data for both historical and recent periods (Figure 2). However, visual inspection of the data reveals clustering around a few localities. Further, historic records do not spatially match recent records, making comparisons difficult. For this dataset, most of the historical records are located around Valladolid and were collected by Enrique Asensio and his collaborators. There has been no recent sampling of bees in this area. However, we found that Enrique systematically sampled seven locations and that additional data were available at the “Museo de Historia Nacional” and other minor collections. Digitization of these records, along with a re-survey of these locations provided an excellent dataset for a before and after comparison of bee communities at these specific locations. Interestingly, this localities have experienced all large agricultural intensification expand

In brief, we cleaned taxonomical names using taxize (**???**), checked sampling completeness for both time periods and compared species richness for each site before and after 1980 with a paired t-test. We found that there is a trend to find a reduced number of species per site (P = 0.058). However, this is higlhly dependant on the site as 2 out of 3 sites show no richness declines. However, there are clear groups of species suffereing larger declines. Andrenids and its parasites being among the losers and Halictids among the winners. This is in accordance with findings elsewhere (e.g. **???**) (appendix?).

## when .  
## 1 asensio 311  
## 2 now 134

## when .  
## 1 asensio 47  
## 2 now 29

## genus asensio now  
## 1 Afranthidium 1 0  
## 3 Ammobates 1 0  
## 4 Ammobatoides 1 0  
## 8 Anthocopa 1 0  
## 10 Biastes 1 0  
## 12 Camptopaeum 1 0  
## 15 Chelostoma 1 0  
## 19 Dioxys 1 0  
## 20 Dufourea 1 0  
## 21 Epeolus 1 0  
## 27 Icteranthidium 1 0  
## 32 Melitta 1 0  
## 33 Melitturga 1 0  
## 35 Nomia 1 0  
## 38 Panurginus 1 0  
## 40 Prosopis 1 0  
## 45 Systropha 1 0  
## 46 Tetralonia 1 0  
## 47 Thyreus 1 0  
## 48 Trachusa 1 0

## genus asensio now  
## 1 Afranthidium 1 0  
## 2 Amegilla 4 1  
## 3 Ammobates 2 0  
## 4 Ammobatoides 1 0  
## 5 Andrena 54 14  
## 6 Anthidiellum 2 1  
## 7 Anthidium 7 2  
## 8 Anthocopa 3 0  
## 9 Anthophora 19 10  
## 10 Biastes 1 0  
## 11 Bombus 6 7  
## 12 Camptopaeum 1 0  
## 13 Ceratina 7 4  
## 14 Chalicodoma 0 2  
## 15 Chelostoma 2 0  
## 16 Coelioxys 8 2  
## 17 Colletes 11 4  
## 18 Dasypoda 4 3  
## 19 Dioxys 2 0  
## 20 Dufourea 1 0  
## 21 Epeolus 1 0  
## 22 Eucera 9 6  
## 23 Halictus 14 10  
## 24 Heriades 2 1  
## 25 Hoplitis 5 3  
## 26 Hylaeus 3 8  
## 27 Icteranthidium 1 0  
## 28 Lasioglossum 33 21  
## 29 Lithurgus 4 2  
## 30 Megachile 15 3  
## 31 Melecta 3 2  
## 32 Melitta 2 0  
## 33 Melitturga 1 0  
## 34 Nomada 20 3  
## 35 Nomia 1 0  
## 36 Nomioides 2 1  
## 37 Osmia 15 8  
## 38 Panurginus 2 0  
## 39 Panurgus 4 4  
## 40 Prosopis 7 0  
## 41 Pseudapis 0 1  
## 42 Pseudoanthidium 2 1  
## 43 Sphecodes 10 5  
## 44 Stelis 4 2  
## 45 Systropha 2 0  
## 46 Tetralonia 5 0  
## 47 Thyreus 3 0  
## 48 Trachusa 1 0  
## 49 Xylocopa 4 3

##   
## Paired t-test  
##   
## data: asensio[c(1, 2, 3, 5, 6, 7)] and now[c(1, 2, 3, 5, 6, 7)]  
## t = 2.4452, df = 5, p-value = 0.05828  
## alternative hypothesis: true difference in means is not equal to 0  
## 95 percent confidence interval:  
## -1.039128 41.583404  
## sample estimates:  
## mean of the differences   
## 20.27214

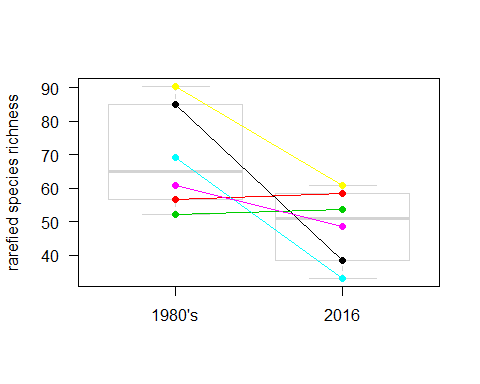


Figure 3. Rarefied richness at the 6 plots resurveyed.

# Case study two: New Zealand

In contrast to Spain, New Zealand is an isolated oceanic archipelago, with a distinctive pollinator biota and a unique history of human occupation. Much of New Zealand’s pollinator fauna is also relatively depauperate. For example, New Zealand has only 27 species of native bees [41], which is a fraction of nearby Australia’s c. 1600 species [# **???**]. However, New Zealand has a surprisingly high diversity of fly (Diptera) pollinators, which are important pollinators in many ecosystems [42]. Thus, New Zealand provides a unique system to study long-term changes in pollinator communities, and is unlike continental Europe and the US, which have been the focus of an overwhelming majority of pollinator decline studies.

In global terms, human colonisation of New Zealand was relatively recent (c. 740 y) [43]. Before human arrival, New Zealand was predominately forested, but has since been dramatically altered by people. Early Māori settlers cleared forests by burning and more recently, European colonists cleared large tracts of remaining forests and drained low-lying wetlands for agriculture, mostly before 1900 [44]. Therefore, human activity likely affected pollinator communities in New Zealand long before surveys and collections began. Nevertheless, we can use museum records to identify trends in pollinator communities during New Zealand’s more recent history.

We used New Zealand bee collection records gathered from multiple sources, including university, research institute, museum and private collections. Collection records from the New Zealand Arthropod Collection (NZAC) are freely available online (<https://scd.landcareresearch.co.nz/>). Fly pollinator data was obtained from six participating New Zealand museums need to list in the acknowledgments and covers two families (Calliphoridae and Syrphidae) that contain important fly pollinators. Collections for the bee and fly datasets span over 100 years (early 1900s to late 2000s).

We follow Bartomeus et al. 2013a protocol to analysze this data. First, we filtered our original datasets so that data used for analyses only included independent collection events. To do this, we removed specimens collected at the same location, on the same date, and by the same collector. We found our data had reasonable coverage across time periods, although there was a peak in collection occurrences from 1960-1980. We accounted for differences in collection effort through binning collection records by time so that each bin had a similar number of records but a different number of years. We then estimated richness for each time period bin by rarefying all bins to an equal number of specimens and calculated the mean species richness ±SE for each bin. Finally, we estimated the significance of change in richness using a permutation test that randomly reordered time periods and calculated the correlation between time period and species richness. Thus, reported P-values were the proportion of permutations that had higher or lower correlations compared to the correlation between richness and the actual chronological time period sequence.

Second, to determine if the probability of finding a species in the collection changed over time, we used a general linear model with a binomial distribution and a logit link. For species that showed overdispersion, we used a quasi-binomial distribution. Further, we only included species in this analysis for which we had 30 or more records. To account for differences in sampling effort between years, we weighted each year by the total number of samples collected in that year.

We found that rarefied richness for both native and exotic bees increased overtime, but these trends were non-significant (P-values for both groups > 0.05). In contrast, native fly richness declined, whereas exotic fly richness increased, although results for these groups were also non-significant (P-values for both groups > 0.05). Note that rarefied richness is sensitive to species evenness, so increases in rarefied richness over time may actually indicate increased species evenness.

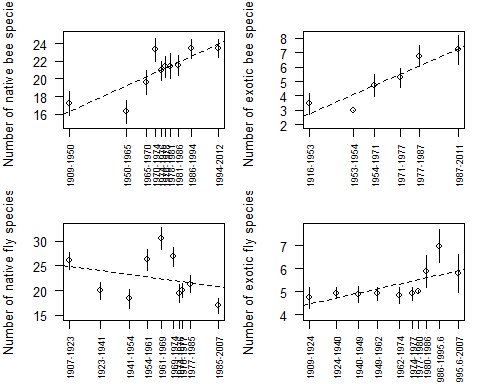


Figure 4. Changes in rarefied species richness for different pollinator groups in New Zealand over time. All trends were non-significant (α = 0.05).

However, at the species level, we found that 10 out of 27 bee species increased in relative abundance over time (nine native and one exotic) and three bee species declined in relative abundance (one native and two exotic) (Figure 3). Interestingly, the two exotic bee species that declined in relative abundance were both in the genus Bombus, intentionally introduced into New Zealand for the pollination of crops. Native bees that increased in relative abundance were mostly from the genus Leioproctus. Only two out of 14 fly species increased in relative abundance, both of which were exotic, whereas four species decreased in abundance (three native and one exotic). Native flies that decreased in relative abundance were all Syrphidae in the genus Helophilus.

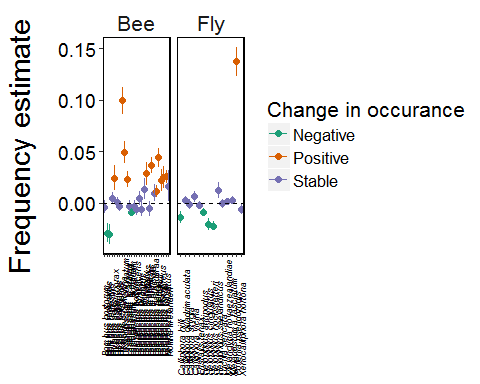


Figure 5. Model estimated changes (± 1 SE) in the relative occurrence frequency for different New Zealand bee and fly species in museum collections over time.

# Beyond species occurrences

A recent study found that more than 90% of the papers studying pollinator responses to land-use change focused solely on richness and abundance descriptors [**???**]. But in addition to local (alpha) diversity and regional (gamma) diversity, we need to assess changes in turnover between sites (beta diversity). Environmental changes often result in a few “winner” species and many species becoming “losers” [45]. Identifying winners and losers is critical as the few winners are often exotic and represent a subset of traits that facilitate survival in highly modified environments [46]. These changes can have important effects for pollination of native plant species and crops.

But museum specimen collections can provide much more information besides species occurrence records, providing such information is captured when digitizing collections. This is particularly important for identifying mechanisms of decline and adaptation. For example, recording the date of collection is particularly important for tracking of phenological advances congruent with contemporary climate change [47]. In addition, pollinator specimen labels often include information about the host plant on which the specimen was collected. This information critical for understanding past and present species interactions [48]. Regardless of this information, bee specimens often contain pollen loads trapped in the hairs, making possible to reconstruct past visitation events [49]. Finally, museum specimens can be measured to track evolutionary changes by measuring specific specimen traits. This has been already explored to show tongue length [50] and body size [51] shrinkage with climate and land use change.

# Conclucions

As illustrated in our examples, unleashing the power of museum collection data to answer pressing questions is at our hands, but requires the coordinated effort of many actors. Using two case studies, we show that collaboration with both museum curators and ecologists is key to adequately understanding the data and treating it appropriately. Researchers and curators should aim to make digitalized data readily available and easy to share. Centralization of regional and national museum data in existing global platforms such as GBIF would facilitate free and widespread access. However, specific datasets can also be stored in different webpages or database repositories (e.g. Universities and museum webpages, Dryad) as far as they are well documented and can be easely retrived and combined with other datasets using open science tools [52].

We also need to revolutionize the way that researchers collaborate with museums, which should start with fostering healthy bidirectional relationships. For instance, ecological researchers collect massive amounts of specimens, but these are often inappropriately vouchered ([53]; [54]), rendering them less useful for future research. To improve this, strong communication between museums and researchers is required, but this will only be achieved if there is not adequate funding, and recognition that accurate data recording and long-term preservation are critical for research [55].

Ultimately, to identify global trends in pollinator declines we require robust data, collected from diverse geographic regions. Further, it is crucial that data are analysed appropriately. This requires researches to identify biases in the data and fill taxonomic and geographic gaps in knowledge of pollinators status where possible. We need to place increased emphasis on quantifying pollinator declines in regions outside of the US and Europe and for pollinator groups other than bees. For the US and Europe there have been few regional bee extinctions [19,21], but in disturbed ecosystems declines are widespread [14,16,19]. For most other pollinator taxa and regions throughout the world we know almost nothing. Moving forward, the first step for many taxa will be to identify and describe species. Only then can we begin to document declines.

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