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The Decline of Plant Collecting in the United States: A Threat to the Infrastructure of Biodiversity Studies

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ABSTRACT. Collections of plant specimens are the basic infrastructure for all studies of plant diversity, but there is concern that plant collecting is in decline. We acquired collection data from a diverse sample of 71 herbaria to test whether there is a decrease in rates of local collecting in the United States. The recorded data were the decade of collection for all specimens of nine exemplar genera from the local region of the herbarium. All analyses showed evidence of a decline in local collecting. We found that the temporal pattern of collecting varied considerably from herbarium to herbarium, but that more herbaria showed a decreasing trend than an increasing trend. The total accumulation of specimens is in decline and only 21% of the sampled herbaria reached their peaks in local collecting activity in the last 20 years. Furthermore, two thirds of the herbaria acquired fewer locally-collected specimens in the last two decades than in the prior two. These trends were consistent over all size classes of herbaria and over herbaria from all regions, though they were less severe in the Mountain region herbaria. Tests for bias indicated that our sample of herbaria was more active than typical, thus our conclusions should be considered a conservative estimate of decline.

The importance of plant collecting in cataloguing biodiversity cannot be overstated: specimens are the very basis of floristic and plant taxonomic science, and as such provide the foundation of nomenclature, the basis for identification, the common reference for communication, the vouchers for floras, and the tools for teaching. All fields of biological science from systematics and evolution to ecology and even physiology and molecular biology are ultimately dependent on collections, not just for application of names, but as the basis for referencing all aspects of biodiversity. Most specimens are accumulated during the course of floristic studies. Floristic efforts document occurrences with specimens, providing the raw data needed for understanding all geographic aspects of plant diversity. Thus, floristic studies are the foundation for ecological and biogeographic research. Furthermore, sound floristic knowledge is prerequisite for making informed land-management and conservation decisions (e.g., Ertter 2000a, b; Heywood 2001; Norris et al. 2001).

The present study examines levels of local plant collecting in the U.S. Concern is accumulating that plant collecting is in decline (e.g., Cotterill et al. 1994; Ertter 2000a; Funk and Morin 2000; Norris et al. 2001). Published studies assessing the rate of collecting over time are scarce: declines have been documented for plants from the Ames Iowa region (Norris et al. 2001) and for birds deposited in the U.S. National Museum of Natural History (Winker 1996). Vertebrate collecting may have declined in part because of pressure from animal rights groups, which is a factor that does not apply to plant collecting.

Whether plant collecting is in decline has remained a matter of speculation because comprehensive studies of rates of plant collecting have not been heretofore undertaken. We have compiled data to determine if there is a decrease in acquisition of plant collections in U.S. herbaria (throughout this paper, 'collecting' is assessed by those specimens actually accessioned into herbaria, whether through the collecting efforts of a given herbarium's personnel and students or by gift or exchange from other institutions).

Our approach was simple: we recorded the decade of collection for all specimens of nine exemplar taxa from 71 herbaria. We specifically addressed the following questions: 1) How does the temporal pattern of accumulation of specimens compare from herbarium to herbarium? 2) What is the total pattern of accumulation of specimens in the U.S. over time? 3) When did U.S. institutions reach their peaks in activity? 4) Over the last 40 year interval, is local collecting increasing or decreasing? 5) Are there regional differences in patterns of local collecting? And finally, 6) Is collecting activity related to herbarium size? We present the results of these analyses and discuss the limitations of these data and the need for additional study of patterns of collecting. In a companion commentary in this issue (Prather et al. 2004) we discuss the implications of our results.

MATERIALS AND METHODS

Herbaria are strikingly diverse in many features that might affect collecting, such as history, mission, size, affiliation, and staffing level. Therefore, any attempt to accurately address the question of whether plant collections and specimen acquisition rates are decreasing in recent times will be affected by the choice of herbaria that are sampled. In order to reduce any bias caused by these factors, we made every effort not to discriminate in herbarium choice—we included every institution we could (Table 1). We spe-

TABLE 1. Herbaria included in the survey of collecting trends, their location, and the number of specimens sampled from each. Peak decade indicates the decade during which the largest number of specimens was collected. The herbaria were divided into three size classes: small (S) herbaria harbor less than 50,000 specimens, medium herbaria (M) harbor 50,000 to 499,999, and large herbaria (L) harbor 500,000 or more. Increasing (I) indicates that the herbarium has more specimens from the last two decades than from the prior two, and decreasing (D) indicates the reverse. See text for details. [a] VDB was recently moved from Nashville, TN and is now housed at the Botanical Research Institute of Texas; only the Tennessee collections were examined for this study.

Acronym	Location	# specimens sampled	Peak Decade	Size Class	Increasing or decreasing
ADR	Adrian, MI	141	1960s	S	D
ALA	Fairbanks, AK	1,127	1990s	M	I
ALBC	Albion, MI	169	1920s	S	I
APSC	Clarksville, TN	306	1960s	S	D
ARIZ	Tucson, AZ	1,415	1930s	M	D
ASU	Tempe, AZ	1,105	1960s	M	D
AUA	Auburn, AL	514	1970s	M	D
BH	Ithaca, NY	2,635	1910s	L	I
BLH	Bloomfield Hills, MI	1,254	1930s	M	I
BRIT	Fort Worth, TX	1,271	1940s	L	D
CHSC	Chico, CA	674	1990s	M	I
CLEMS	Clemson, SC	450	1970s	M	I
CMC	Mount Pleasant, MI	560	1960s	S	D
COLO	Boulder, CO	1,758	1980s	L	I
CS	Fort Collins, CO	1,013	1980s	M	D
EMC	Ypsilanti, MI	240	1970s	S	D
Erskine College	Due West, SC	27	1960s	S	D
F	Chicago, IL	889	1900s	L	D
FHKSC	Hays, KS	106	1960s	S	D
FLAS	Gainesville, FL	521	1930s	M	D
FTG	Miami, FL	123	1980s	M	I
GREE	Greeley, CO	429	1990s	S	D
HCH	Lewiston, ID	76	1990s	S	I
HWBA	Atchison, KS	9	1950s	S	D
ILLS	Champaign, IL	3,251	1950s	M	D
JEPS	Berkeley, CA	782	1930s	M	D
KANU	Lawrence, KS	1,587	1970s	M	D
KBSMS	Hickory Corners, MI	77	1970s	S	D
KHD	Denver, CO	323	1990s	M	I
KSC	Manhattan, KS	610	1890s	M	D
KSP	Pittsburg, KS	228	1960s	S	D
KSTC	Emporia, KS	510	1960s	M	D
LSU	Baton Rouge, LA	468	1970s	M	D
MICH	Ann Arbor, MI	2,579	1950s	L	I
MIN	St. Paul, MN	5,148	1930s	L	I
MISS	University, MS	425	1960s	M	D
MO	Saint Louis, MO	2,077	1930s	L	I
MOR	Lisle, IL	352	1970s	M	I
MSC	East Lansing, MI	1,828	1970s	M	D
NEB	Lincoln, NE	1,085	1990s	M	I
NEBC	Cambridge, MA	6,198	1910s	M	D
NHA	Durham, NH	1,017	1950s	M	D
NMC	Las Cruces, NM	317	1900s	M	I
OKL	Norman, OK	1,275	1930s	M	D
OKLA	Stillwater, OK	655	1950s	M	D
OSC-ORE-WILLU	Corvallis, OR	2,815	1930s	M	D
Rice Creek Field Station	Oswego, NY	31	1970s	S	D
RM	Laramie, WY	7,944	1990s	L	I
RSA	Claremont, CA	2,613	1930s	L	D
SWT	San Marcos, TX	184	1980s	S	I
TAES	College Station, TX	578	1930s	M	D
TAIC	Kingsville, TX	77	1920s	S	I
TAMU	College Station, TX	263	1980s	S	I
TEX-LL	Austin, TX	2,588	1950s	L	D
TULS	Tulsa, OK	196	1980s	S	I
UC	Berkeley, CA	2,304	1930s	L	D
UMBS	Pellston, MI	251	1950s	S	D
UMF	Flint, MI	100	1990s	S	I

TABLE 1. Continued.

Acronym	Location	# specimens sampled	Peak Decade	Size Class	Increasing or decreasing
UMO	Columbia, MO	1,072	1950s	M	D
UNA	Tuscaloosa, AL	392	1970s	M	D
UNM	Albuquerque, NM	1,520	1960s	M	D
US	Washington, DC	949	1910s	L	D
UTC	Logan, UT	4,036	1930s	M	D
VDB	Nashville, TN (Fort Worth, TX)[a]	983	1940s	M	D
WASH	Topeka, KS	68	1890s/1920s	S	N/A
WILLI	Williamsburg, VA	684	1970s	M	D
WIS	Madison, WI	3,902	1960s	L	D
WMU	Kalamazoo, MI	437	1970s	S	D
WUD	Detroit, MI	304	1950s	S	D
WVA	Morgantown, WV	1,379	1930s	M	D
YUO	Youngstown, OH	727	1980s	M	I

cifically included our home institutions, other herbaria that were nearby (regardless of size, activity level, or any other factor), herbaria that we traveled to during the course of this project, herbaria of which we were aware that had label information databased, and herbaria whose staff we could prevail upon to collect the data for us. As a result of these efforts we have included very small and very large collections, herbaria from public and private institutions, herbaria at universities, museums, and botanical gardens, and herbaria from 30 states and the District of Columbia (Fig. 1).

We chose to sample only collections originating from within the local region of the herbarium. Counting only local specimens may have helped prevent inflation of numbers that might have arisen from re-sampling duplicates of the same collection that were widely distributed. Furthermore, most herbaria file in-state collections separately from out-of-state collections, so acquiring the data from in-state collections required only going through in-state folders. For most herbaria, local was defined as in-state. For NEBC (standardized herbarium codes follow Holmgren et al. 1990), collections from the states of Connecticut, Maine, Massachusetts, New Hampshire, Rhode Island, and Vermont were included. For YUO, collections from Ohio, Pennsylvania, and West Virginia were included. For US, we included collections from the D.C. Herbarium (parts of Maryland and Virginia, plus the District of Columbia).

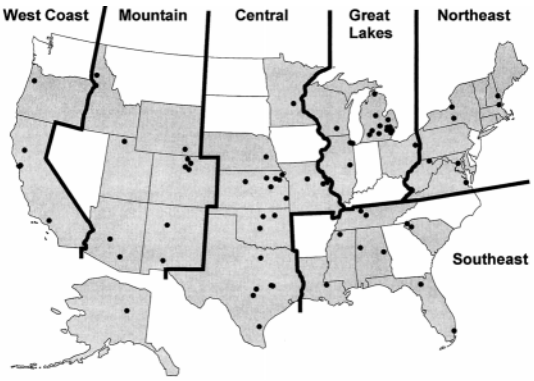

FIG. 1. Location of the 71 herbaria sampled in this study, indicated by dots. The divisions used for analyses by geographic regions are indicated by the bold lines (the Alaskan herbarium was not included in regional analysis). States from which specimens were included are indicated by gray shading.

Thus, specimens from a total of 36 states, plus the District of Columbia, were included in our analysis (Fig. 1).

Because a large backlog of specimens to be accessioned could affect our results we inquired into the amount of unprocessed specimens at the herbaria sampled. Most herbaria had either a small backlog of local collections or none at all. In two cases (MO and RM), we were able to include the backlog that was in the process of being accessioned. In other cases where there was a backlog of local collections, it was considered to be insignificant in relation to the total collection size. There is one exception: JEPS has considerable backlog of California specimens from recent years (B. Ertter, pers. comm.) potentially impacting the results for that herbarium. In addition to the current backlog, many of the herbaria will eventually receive additional specimens from collectors. The observed results might be slightly impacted by these small backlogs or specimens not yet acquired, mostly, but not exclusively, from recent decades.

We chose nine genera as exemplars: *Amelanchier* Medik. (Rosaceae), *Antennaria* Gaertn. (Asteraceae), *Corallorhiza* Châtel. (Orchidaceae), *Juniperus* Tourn. ex L. (Cupressaceae), *Leersia* Sol. ex Sw. (Poaceae), *Nuphar* Sibth. & Sm. (Nymphaceae), *Phlox* L. (including *Microsteris* Greene; Polemoniaceae), *Populus* L. (Salicaceae), and *Woodsia* R. Br. (Dryopteridaceae). By choosing genera, rather than species, we were able to sample taxa that had broad ranges and we could therefore use the same taxa across the U.S. Furthermore, we were able to choose genera whose limits and taxonomy have been relatively stable, thereby limiting any problems that might arise by nomenclatural issues and idiosyncrasies in herbarium filing.

Our criteria for taxon choice were that the taxa had to represent a diversity of life history traits, habitat preferences, and taxonomic groups. Exemplars were chosen to represent annuals and perennials; herbs, shrubs, and trees; aquatics and terrestrials; and ferns, gymnosperms, monocots and dicots. Each genus occurs throughout the contiguous U.S., and all but *Leersia* also occur in Alaska (we were not able to include any Hawaiian herbaria in our sampling). While it is impossible to choose taxa whose abundance has not changed over time, we purposefully attempted to choose genera that do not have introduced or highly invasive species. Recording data from taxa that were introduced during the time frame considered in our study or that increased in frequency over that time frame would obviously bias our data. We also made an attempt to omit taxa with large numbers of rare or endangered species because a decrease in collecting of those taxa might have occurred in recent decades because of legal or ethical deterrence to collecting. When possible, we omitted cultivated specimens or specimens of cultivars that had escaped.

The data themselves are simply a record of the decade in which all of the local specimens of our nine exemplar genera in each herbarium were collected. For simplicity, a decade begins with years ending in ''0'' and ends with years ending in ''9''. For example, the ''1830s'' begins on 1 Jan 1830 and ends on 31 Dec 1839.

We performed six analyses to understand how levels of local plant collecting have changed over time in the U.S.:

Analysis 1: How Does the Temporal Pattern of Accumulation of Specimens Compare from Herbarium to Herbarium? We tallied the number of specimens of the nine exemplar genera cumulatively, by decade, for each herbarium. This approach provided a graphic description of the collecting pattern over time for each herbarium.

Analysis 2: What is the Total Pattern of Accumulation of Specimens in the U.S. Over Time? We summed the data from all herbaria in a single graph illustrating the pattern of total accumulation of specimens based on all 71 herbaria. Using this approach, it is possible that a single herbarium, if remarkably active during a particular time period, could have a major effect on the overall pattern. This was not merely a hypothetical concern: one herbarium, RM, had a disproportionate effect on this analysis, so the analysis was performed twice, once including this herbarium, and once excluding it (see results). Another limitation of this analysis was that it minimized the contribution of small herbaria, because they each contributed only small amounts to the overall tally of specimens, even though small herbaria often have important collections and can exhibit considerable productivity. Analyses 1, 3, and 4 do not suffer from this limitation.

Analysis 3: When Did U.S. Institutions Reach Their Peaks in Activity? We determined the decade during which each herbarium accessioned its largest number of local specimens, referred to here as the ''peak'' decade, and graphed the number of herbaria that were at their peak during each decade. One herbarium had identical maxima in two decades, so it was plotted as 0.5 in each of the two decades.

Analysis 4: Over the Last 40 Year Interval, is Local Collecting Increasing or Decreasing? In the analyses above, the interpretation is somewhat subjective, because the pattern over time is not always easily interpretable. We preferred a more objective criterion, and one that primarily represented recent activity. Therefore, we compared the total number of specimens from each herbarium collected during the 1960s and 1970s to the total number from the 1980s and 1990s. If the number from the former two decades was greater than that from the latter two, then we scored the herbarium as ''decreasing,'' and if the reverse was true, we scored the herbarium as ''increasing.'' One herbarium, WASH, accessioned no specimens of the exemplar genera over the last 40 years, so it was excluded from this analysis.

We calculated the same statistic for every 40 year interval over the last 100 years (e.g., 1870s plus 1880s versus 1890s plus 1900s; 1880s plus 1890s versus 1900s plus 1910s, etc.) so that we could track the percentage of herbaria in decline over time. Herbaria from which no specimens were recorded over any of the 40 year intervals, or for which equal numbers of specimens were collected in the first and last halves of an interval, were excluded from the calculation for that interval.

Analysis 5: Are There Regional Differences in Patterns of Local Collecting? We also wanted to explore whether the geographic location of the herbaria sampled had an effect on herbarium activity over time. To address this possibility we divided the U.S. into geographic regions and analyzed the data separately by region (Fig. 1). The Alaskan herbarium (ALA) was excluded from this analysis. After defining these regions, we then performed analyses similar to analyses 2, 3, and 4, above, on each geographical subset of data.

Analysis 6: Is Collecting Activity Related to Herbarium Size? To assess whether herbarium size had an effect on patterns of herbarium activity over time, we divided the herbaria among three size classes and re-analyzed the data. Small herbaria were defined as those that house less than 50,000 specimens, medium herbaria as those with 50,000 to 499,999 specimens, and large herbaria as those with 500,000 or more. Classification by size was based on total numbers of specimens as reported by staff of each herbarium. We performed analyses similar to analyses 2, 3, and 4, above, on each size class.

Accuracy of Sampling and Potential Bias. We tested the adequacy of our taxon choice and sample size by tabulating the *total* local specimens in four herbaria that had their specimens databased, and correlating the distribution over time of the total collections to the distribution of the specimens in the nine exemplar genera. The herbaria used for the study were ILLS, JEPS, UC, and the herbarium at Rice Creek Field Station (Oswego State University, New York). UC and JEPS are not totally independent: they are both maintained at the University of California, Berkeley, and they share staff. However, because the collecting patterns are quite different (Fig. 2) we maintained them as separate in this analysis. We performed a preliminary analysis for a fifth, TEX-LL, on all completely databased Texas families, which comprise approximately two thirds of their entire Texas holdings (T. Wendt, pers. comm.).

We tested whether the sample of herbaria included was representative of all herbaria by analyzing the combined herbaria from our home states, Kansas and Michigan, and comparing them to the remainder. We were able to sample a higher proportion of the herbaria in these two states due to their proximity to our home institutions. This analysis allowed us to test whether the herbaria that we sampled were, on average, more active than a more complete set of herbaria, based on the same methods as analysis 4, above.

RESULTS

We sampled 84,001 specimens from 71 herbaria. We recorded data from plants collected after 1999, and often recorded the number of specimens without dates, but these data were not included in the analyses.

Analysis 1: How Does the Temporal Pattern of Accumulation of Specimens Compare from Herbarium to Herbarium? The most striking result from analysis 1 was the diversity of observed patterns (Fig. 2). Each herbarium has a unique history and temporal distribution of collections. Many herbaria have an obvious pattern of a peak in activity in the past, and then a more recent decline (e.g., KSC peaked in the 1890s under the curatorship of A. S. Hitchcock, and has never regained such a high level of activity). Others clearly show increasing rates of collecting into the 1990s (e.g., RM shows a recent explosion in collecting activity due to floristic research supervised by the curator, R. L. Hartman), though the number showing this pattern is fewer. Many herbaria have a more complicated history showing that local collecting can vary remarkably over time and cannot easily be classified as simply increasing or decreasing (e.g., MO has a buildup to two peaks, each associated with a flora of Missouri project).

Analysis 2: What is the Total Pattern of Accumulation of Specimens in the U.S. Over Time? Based on the combined analysis of the total number of specimens by decade (Fig. 3A), no clear pattern of increase or decrease can be observed. Rather, there is an increasing trend in the total number of accumulated specimens until the 1930s. Subsequently, there have been decade to decade fluctuations and no straightforward pattern is apparent. However, more specimens were collected in the 1930s than in any other decade,

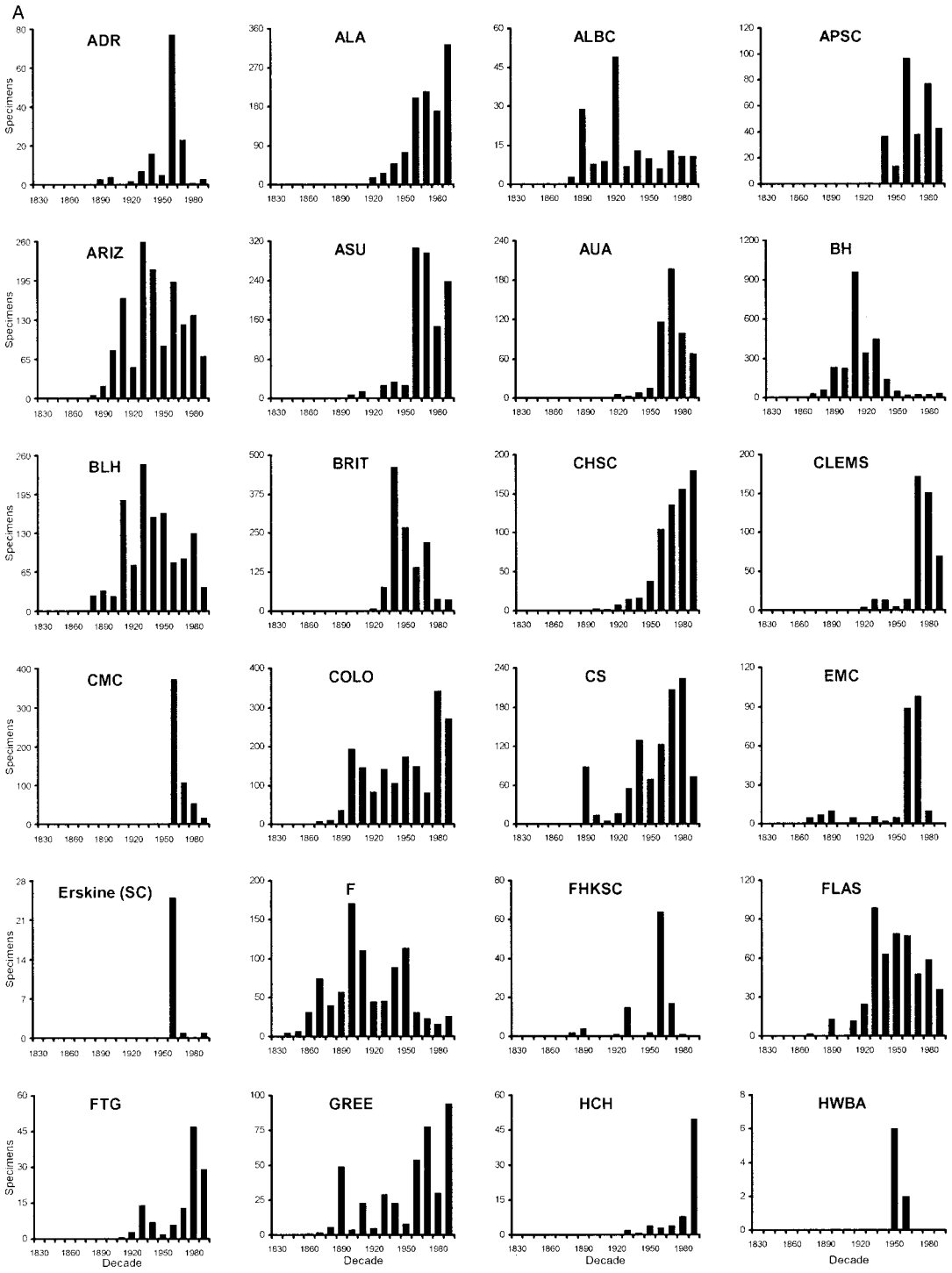

FIG. 2. Accumulation of local specimens of nine exemplar genera by decade for individual herbaria included in the study. Herbaria are alphabetized by their acronym, or name for those that do not have an acronym. The y-axis (number of specimens) is scaled differently from herbarium to herbarium.

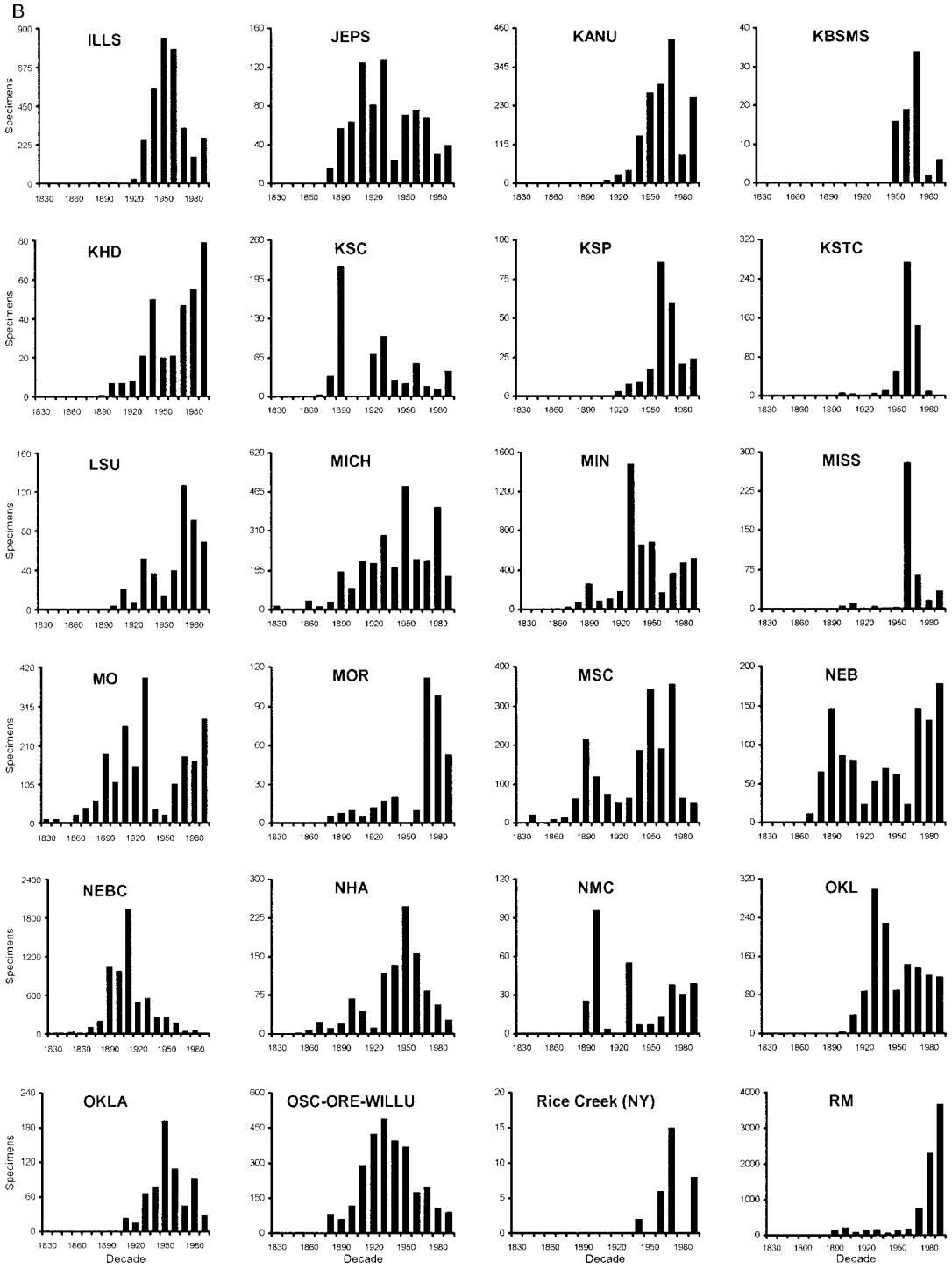

FIG. 2. Continued.

indicating that the number of specimens accessioned into herbaria peaked more than 60 years ago.

Because more individual herbaria show a decreasing pattern, rather than an increasing one (Fig. 2), we expected analysis 2 to show a clearly decreasing pattern. Examination of the data provides a clear reason for why the overall pattern contrasts with the expectation based on patterns of the individual herbaria. A re-

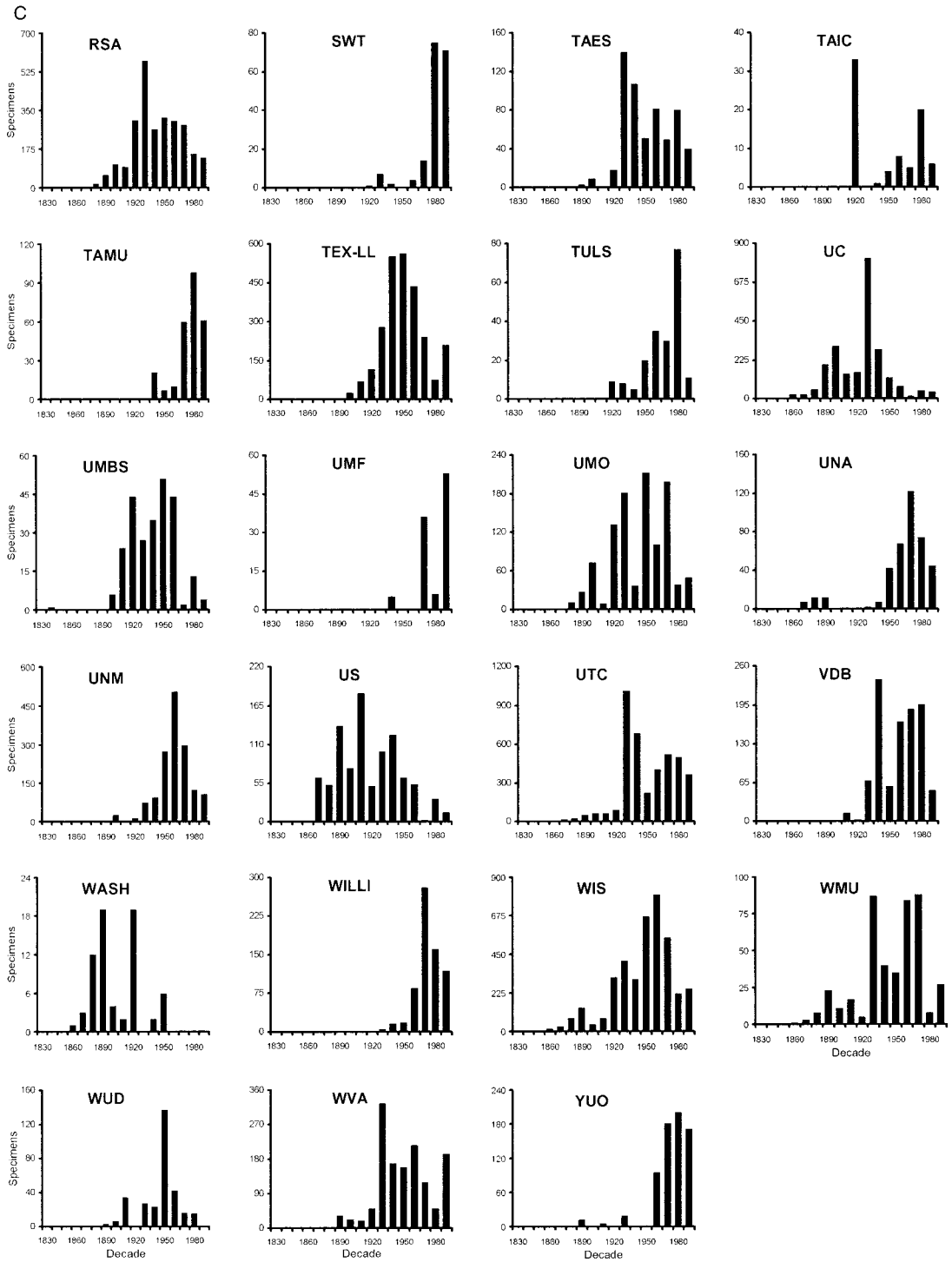

FIG. 2. Continued.

markable number of local specimens have been collected and accessioned into one herbarium, RM, in recent years. In fact, 38% of the total number of 1990s specimens were from RM. The number of specimens in RM from the 1990s (3,677) is over 40 times that of the average for the other 70 herbaria (mean = 87 specimens). Because the data from RM were so anomalous, we excluded RM from this analysis to see what effect

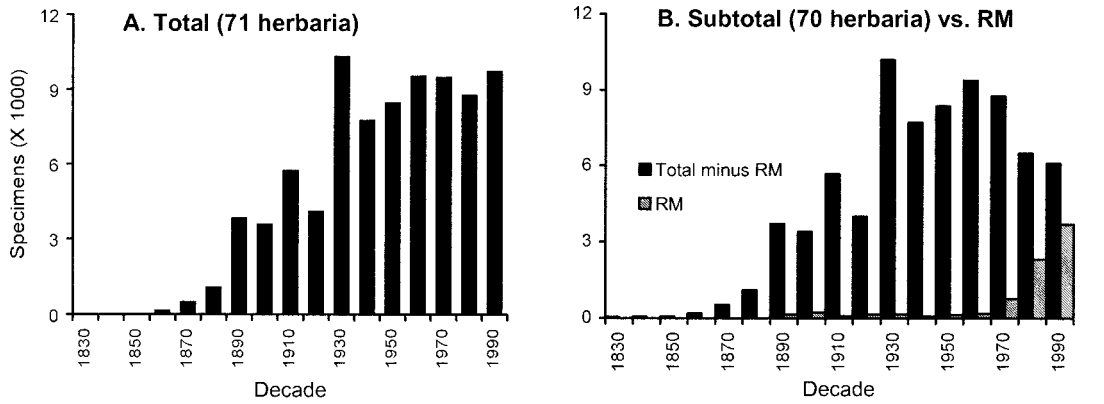

FIG. 3. Total accumulation of sampled specimens by decade for the herbaria included in this survey. A. Total specimens from all 71 herbaria. B. Specimens from RM plotted against the subtotal of the remaining 70 herbaria.

that had on the overall results (Fig. 3B). The change is remarkable; when RM is excluded, the resultant pattern is a steady and marked decrease in collecting since the 1960s.

Analysis 3: When Did U.S. Institutions Reach Their Peaks in Activity? More herbaria peaked in activity in the 1930s than any other decade (Table 1; Fig. 4). This substantiates the results from analysis 2, which showed that more specimens were collected in the 1930s than in any other decade (Fig. 3). Many herbaria also peaked in the 1960s and 1970s. Only 15 of the 71 sampled herbaria (21.1%) peaked in activity during the last two decades. Since the 1950s there have been many herbaria at their peak activity level each year, but there are fewer in the 1980s and 1990s than in the previous three decades, or in the 1930s, which indicates that the number of herbaria at their peak activity level is in decline (Fig. 4).

Analysis 4: Over the Last 40 Year Interval, is Local Collecting Increasing or Decreasing? Two thirds of herbaria sampled (47 of the 70 herbaria included in this analysis, or 67.1%) showed a measured decline in the rate of local collecting from the 1960s through the 1990s (Tables 1, 2). This is a ten-fold increase compared to the earliest 40 year interval for which we calculated the statistic (1870s through 1900s; Fig. 5). There is a clear trend toward a greater percentage of herbaria with declining rates of local collecting over the last 100 years (Fig. 5). Of the ten 40 year intervals measured, only during the most recent two intervals (ending in the 1980s and 1990s), was the percentage of herbaria with declining rates of local collecting greater than 50%.

Analysis 5: Are There Regional Differences in Patterns of Local Collecting? Over the last four decades local collecting is in decline in the majority of herbaria in all regions (Table 2). Activity in Northeast and West

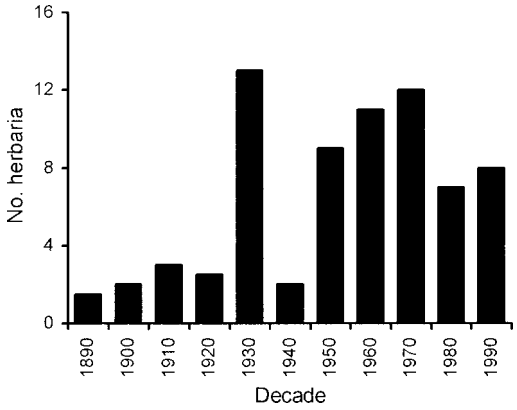

FIG. 4. Herbarium activity over time, as indicated by the number of herbaria sampled that peaked in collecting activity during each decade. See text for details.

TABLE 2. The percentage of herbaria that accessioned decreasing amounts of local specimens over the most recent four decades. Figures are provided for the total set of sampled herbaria, as well as regions, size classes, the two states we sampled most heavily (Kansas and Michigan), and the remaining states. The latter figures provide a test for bias. See text for details.

Herbaria	N	Number Decreasing	% Decreasing
TOTAL (N = 70; WASH excluded)		47	67.1
Region (N = 70; ALA excluded)			
Great Lakes	17	11	64.7
Central	20	12	60.0
Mountain	11	6	54.5
Northeast	7	6	85.7
Southeast	10	8	80.0
West Coast	5	4	80.0
Size Class (N = 70)			
Small	21	14	66.7
Medium	36	26	72.2
Large	13	7	53.8
KS & MI	19	14	73.7
Non-KS & MI	51	33	64.7

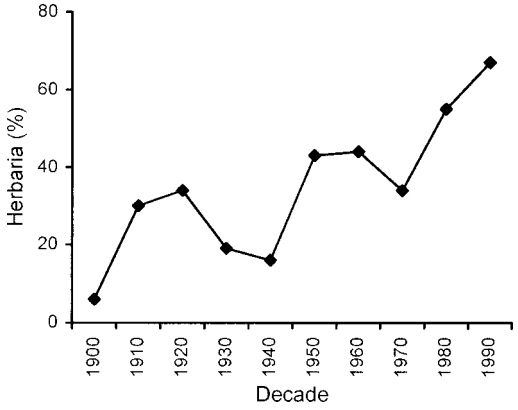

FIG. 5. The percentage of herbaria that were accessioning decreasing amounts of local specimens over time based on activity over 40 year intervals. See text for details. The x-axis indicates the ultimate decade of each 40 year interval.

Coast herbaria declined earlier than in those from other regions, based on total accumulation of specimens and the timing of their peak activity (Fig. 6A–F), and a high percentage of herbaria in those regions exhibited decreasing levels of local collecting (85.7 and 80.0%, respectively; Table 2). A high percentage of Southeast herbaria likewise exhibited decreasing levels of local collecting (80.0%; Table 2), even though the total accumulation of specimens peaked relatively recently and most herbaria in that region reached their peak activity in the 1960s and 1970s (Fig. 6E). Total accumulation of specimens in Central herbaria also peaked relatively early, but peak activity level of these herbaria is more spread out than from other regions (Fig. 6A) and a relatively low percentage of herbaria from the Central region show a decline in local collecting (60.0%; Table 2). Total accumulation of specimens was found to be increasing in the Mountain region and more herbaria from that region reached their peak in the 1990s than in any other decade. Furthermore, even though the majority of herbaria in that region have decreasing rates of local collecting, the percentage of herbaria with decreasing rates is lower in the Mountain region than in any other region (54.5%; Table 2).

Analysis 6: Is Collecting Activity Related to Herbarium Size? Total accumulation of specimens from herbaria of all size classes was found to be in decline, if RM is excluded from the analysis of large herbaria (Fig. 7A–D). The majority of herbaria from all size classes peaked in activity prior to 1970 (Fig. 7). Perhaps most telling, the majority of herbaria from all size classes had decreasing rates of local collecting (Table 2), indicating that local collecting is in decline regardless of herbarium size.

Accuracy of Sampling and Potential Bias. Based on our correlation study, our data accurately depict the general historical patterns of collecting (Table 3; Figs. 8, 9). Our data from the nine exemplar genera were highly correlated with the distribution of the data from the total collections for the five herbaria that were tested ($r^2 \geq 0.85$, $p<0.0001$). An encouraging note is that this was the case even for the smallest of the five herbaria, Rice Creek Field Station: only 31 of 2117 specimens were distributed among our exemplar genera, yet the correlation was strong ($r^2 = 0.85$). However, even though the data are highly correlated, and should thus represent an accurate picture of collecting for each herbarium, it is important to note that the exemplar data and the total data do not always correspond perfectly. For example, the exemplar data indicate that TEX-LL peaked in the 1950s, yet a peak in the 1940s is indicated by a much larger sample of their specimens (Fig. 9B).

As of the 1990s, local collecting was in decline in 73.7% of the Kansas and Michigan herbaria sampled, but only in 64.7 % of the remainder (Table 2). The higher percentage of herbaria in decline in the regions where we sampled most thoroughly suggests that our overall sample may be biased toward more active herbaria.

DISCUSSION

Local Collecting is in Decline. Our data provide clear and unambiguous evidence that local collecting is in decline in the U.S. Most herbaria are not accessioning local specimens at a rate as high as in the past (Fig. 2), the total number of specimens collected from local floras is in decline (Fig. 3), fewer herbaria peaked in activity in the last two decades than in earlier decades (Table 1; Fig. 4), and finally, over the last 40 years local collecting is in decline in more than two thirds of all sampled herbaria (Table 2) and this proportion is higher than at any other time over the last 100 years (Fig. 5).

The majority of herbaria across most geographic regions show a decline in the rates of local collecting over the last 40 years, though it is more pronounced in some areas than in others (Table 2). It is not surprising that the Northeast herbaria peaked earlier than those in most regions. These herbaria were generally established earlier and many floras were published for this region long ago, which fostered the impression that the flora has been well-known for some time. It is somewhat surprising, though, that the West Coast herbaria also peaked earlier than those from most regions, given their somewhat later establishment and the fact that their diverse flora still harbors many undescribed species (Hartman and Nelson 1998; Ertter 2000a, b). The Central, Great Lakes, and Southeast herbaria peaked somewhat later than the Northeast herbaria (Table 1; Fig. 6), but local collecting is clearly in decline from these regions as well. The herbaria of the Mountain

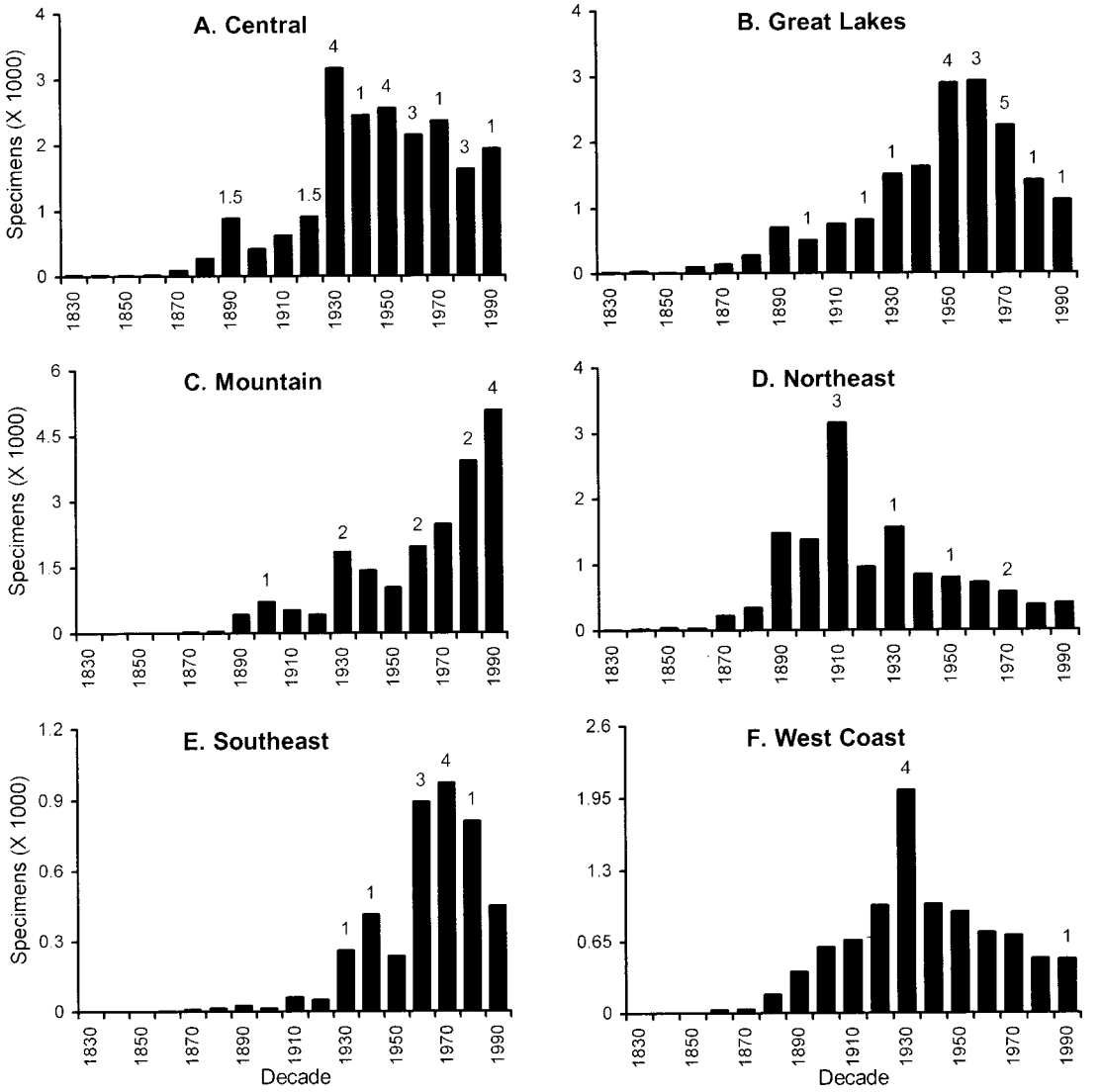

FIG. 6. Regional patterns of specimen accumulation (see Fig. 1 for regional boundaries) based on numbers of specimens of nine exemplar genera plotted by decade. The number of herbaria from each region at their peak activity level in each decade is given above the histogram bars. A. Central herbaria. B. Great Lakes herbaria. C. Mountain herbaria. D. Northeast herbaria. E. Southeast herbaria. F. West Coast herbaria.

region, however, are more active than herbaria in the other regions. Total accessions from this region are clearly increasing and more of these herbaria reached their peak activity level in the 1990s than in any other decade (Fig. 6). Despite the relatively positive overall results for herbaria from the Mountain region, it is of great concern that over half the herbaria from this region have decreasing rates of local collecting over the last four decades (Table 2).

Finally, based on our sample, the decline in local collecting is seen in herbaria of all size classes, in roughly equal percentages (Fig. 7, Table 2). Funk and Morin (2000) found that small and medium herbaria (defined slightly differently than in our study) generally tended to be less active than large herbaria, and those results are consistent with ours.

There are no previously published studies that document collecting activity across the U.S. and few that provide any relevant data (but see Norris et al. 2001). However, one very thorough survey of southeastern U.S. herbaria (Funk and Morin 2000) determined that there is cause to be greatly concerned about herbaria and taxonomic endeavors in that region: many southeastern herbaria have closed and dozens more are inactive or are in jeopardy of closing. It is true that in the U.S in the latter half of the 20th century, some her-

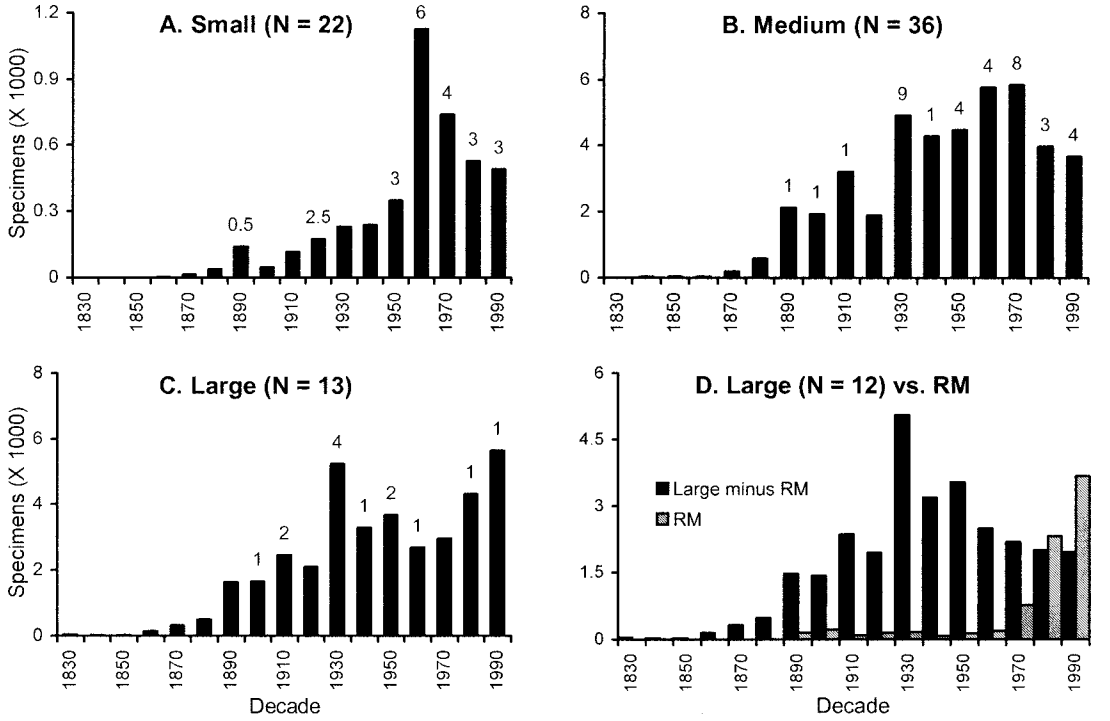

FIG. 7. Total accumulation, by size class (see Table 1), of specimens of nine exemplar genera by decade for the herbaria included in this survey. The number of herbaria in each size class at their peak activity level in each decade is given above the histogram bars. A. Small herbaria. B. Medium herbaria. C. Large herbaria. D. RM plotted separately from the other large herbaria.

baria grew considerably and many herbaria were founded (for instance, see Funk and Morin 2000 regarding southeastern herbaria); yet in spite of this our data show a categorical decline in the rate of local accessions over recent decades.

Potential Biases. Taxon sampling and sample size can be ruled out as potential biases because we found a strong correlation between our samples and the total local collections for the herbaria that we tested (Figs. 8, 9). The data indicated, however, that we may have a biased sample of herbaria and the true decline in local collecting may be greater that what we have uncovered. In our local states (Kansas and Michigan) we were able to sample most herbaria, while outside of our states we only sampled herbaria that we visited (usually in the course of other research), that had databased their collections, or that had sufficient staff to collect the data for us. Thus, we likely ended up with a sample from the most active of all herbaria, except in our local regions. Indeed, 73.7% of herbaria in our home states showed a decline in local collecting, while only 64.7% of the remaining did so (Table 2).

Furthermore, some smaller herbaria that we might have been able to include because of their proximity to our home institutions have been incorporated into some of the larger institutions (e.g., MCT and MCTF have been incorporated into MSC). Because the specimens formerly belonging to these herbaria were included in the totals from the large herbaria, they are incorporated into analyses 1 and 2. However, the incorporated herbaria were not included in analyses 3 and 4 and would certainly have contributed to a stronger decline than the observed one, had they been considered as separate herbaria. Because our inclusion of herbaria is likely biased towards the most active, and because some herbaria that have been assimilated by

TABLE 3. Herbaria included in the test of sampling bias, their total number of local collections, the number of those specimens in the nine exemplar genera, the percentage of the local specimens sampled, and the correlation between the total number of specimens per decade vs. the number of exemplar specimens. All values are highly significant ($p < 0.0001$). [a] For TEX-LL, "total local specimens" is the total number of local specimens presently databased, estimated at about two thirds of the actual total of specimens.

Herbarium Acronym	Total local specimens	Total exemplar specimens	% sampled	r^2
ILLS	178,470	3,243	1.82	1.00
JEPS	85,386	782	0.92	0.86
UC	233,599	2,301	0.99	0.99
Rice Creek Field Station	2,117	31	1.46	0.85
TEX-LL[a]	121,666	2,566	2.11	0.85

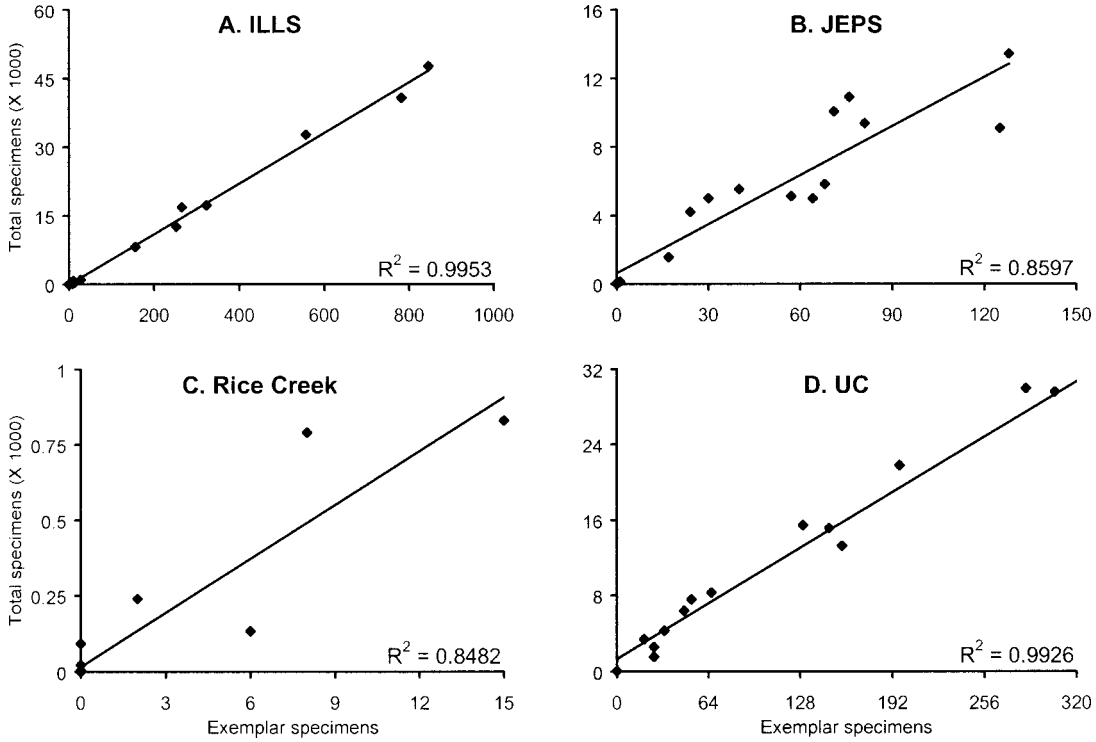

FIG. 8. Comparison of the number of exemplar specimens per decade and the number of total local collections per decade for four herbaria from which complete data were available.

others could not be included in some analyses, *the observed decline in collecting is best viewed as a conservative estimate.*

Caveats on Interpretation. The objective of this study was to explore broad patterns of collecting; interpretation of these data in other contexts may be inappropriate and should be performed only with great caution. For instance, it is inappropriate to use our data for comparisons of the total number of specimens collected from region to region because the proportion of herbaria sampled and the abundance of the exemplar genera are uneven across regions. Likewise, comparison of the numbers of specimens from herbarium to herbarium is inappropriate because of variation in the

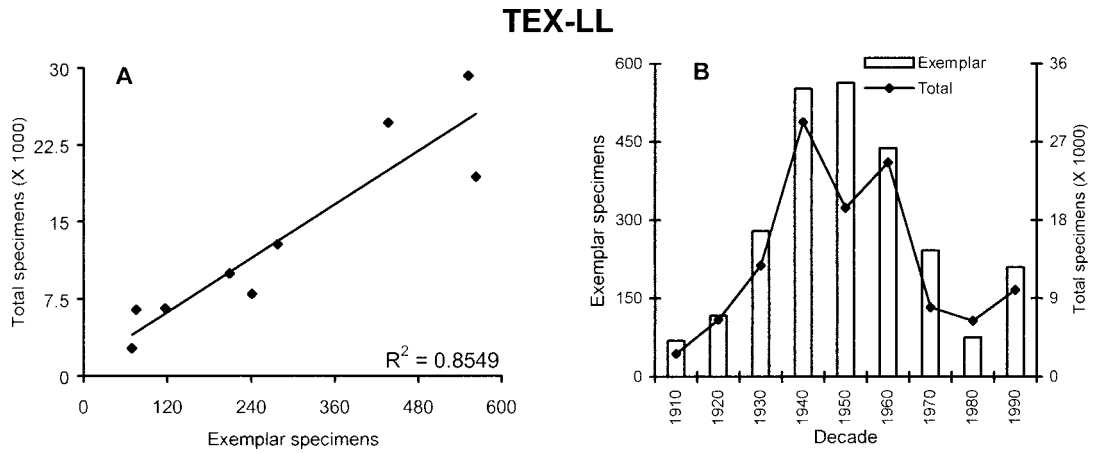

FIG. 9. Comparison of the number of exemplar specimens per decade and the number of total number of databased local collections (estimated to be two thirds of actual total) per decade for TEX-LL. A. Total databased and exemplar specimens plotted against one another. B. Total and exemplar specimens overlaid on one another. The y-axis to the left is the scale for the exemplar specimens, shown as bars, and the y-axis to the right is the scale for the total specimens, plotted as a line.

relative proportions sampled. Furthermore, the pattern of local collecting may be unrelated to total herbarium growth, because many of the herbaria sampled have active collecting or exchange programs that provide specimens from outside their local regions.

Our intent is not to portray any herbarium negatively, and before any reader assumes so, we encourage them to examine the data from our own home institutions (KSC and MSC; Table 1; Fig. 2). In fact, the paucity of recent collections from our own herbaria was one of the factors that inspired this study in the first place. We explicitly discourage others from using our results to criticize individual programs—this study documents the broad decline in local collecting across the U.S. and was not designed as a vehicle for comparison of activity from herbarium to herbarium.

To fully understand the collecting patterns within individual herbaria, more thorough sampling and more detailed analyses would be required. In fact, a promising avenue of future research is careful study of collecting activity in individual herbaria and those of particular states and regions (e.g., Funk and Morin 2000). Given the level of our data acquisition (nine exemplar genera, with collecting activity recorded only to decade), there was certainly some ''noise'' in the data. In fact, discussions with other curators have led us to believe that most individual herbaria have patterns of collecting that cannot be thoroughly summarized by the simplistic data presented here. This is an inherent consequence of sampling. For example, in a few instances, we noted that our sample was influenced by a particular collector, associated with an herbarium, who focused on one of our exemplar genera during a particular decade. These instances were few, and we are confident that they had little, if any, impact on the overall results. We have also shown that our estimate of the peak decade may be inaccurate in some cases (e.g., TEX-LL; Fig. 9B). Where more than one herbarium in a state was sampled, it is possible that there might be overlap in collections because of duplicates sent for exchange. These and other potential problems could not be fully explored in this broad study, but we are confident in the *overall* patterns observed from our analyses.

Summary. We have documented, for the first time, an unambiguous decline in vascular plant collecting in the U.S. It is likely inappropriate to extrapolate these results to other countries or groups of taxa, yet in most cases the situation is probably more bleak. The U.S. has one of the best known floras in the world, and vascular plants are among the best known organisms. Yet our knowledge is far from complete and the flora is continuously changing, and perhaps dramatically so. We're doing an inadequate job of documenting changes to some of the best known organisms in our own backyard. The decline in local collecting has serious implications for systematic studies as well as conservation and land management. We elaborate on these implications and points and discuss potential causes of the decline in collecting, as well as some potential solutions in the companion commentary (Prather et al. 2004).

Finally, we suggest that further study into patterns of collecting is sorely needed. For instance, it is important to know what specific factors contribute to declining rates of collecting. Could it be simply that the number of floristic projects is in decline, while ''background'' collecting continues, or is ''background'' collecting also in decline? Are fewer plant collectors being trained, and what effects might this have had? Is the observed change attributable to fewer contributions from both professional and non-professional collectors? We also need to consider that some collecting will yield higher quality specimens, such as those from poorly known habitats or geographical areas. In contrast, early documentation of non-natives is important for control, but the initial introduction is most likely to happen in places least likely to be studied by botanists, such as shipyards and cultivated lands. How might the need to explore poorly known areas be balanced against the need to collect in areas where non-natives are most likely to be introduced? From a broader perspective, it is extremely important to know if collecting in other areas is in decline, especially tropical regions. This study is but one small contribution to the body of knowledge we need to effectively focus future floristic research, and we hope that our work will stimulate further studies on related topics.

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