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Past forward: Recommendations from historical ecology for ecosystem management

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A R T I C L E I N F O

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A B S T R A C T

In the context of accelerating environmental change, there is an urgent need to identify ecosystem conservation, restoration, and management strategies likely to support biodiverse and adaptive ecosystems into the future. The field of historical ecology has generated a substantial body of recommendations for ecosystem management, yet these insights have never been synthesized. We reviewed >200 historical ecology studies and analyzed recommendations for ecosystem management emerging from the field. The majority of studies (~90%) derived from North American and Europe, with forests being the focus of nearly half (48%) of all papers. Papers emphasized the need to protect and restore both habitat remnants and modified ecosystems in management, the value of ecosystems as cultural landscapes, and the importance of adopting a landscape-scale perspective for ecosystem management. Nearly one-quarter contained a recommendation that challenged status quo management, underscoring the value of a historical perspective in setting management goals, strategies, and targets. Fewer than 12% of papers contained recommendations that explicitly addressed ongoing or projected climate change, suggesting opportunities to integrate findings from historical ecology with other perspectives to create forward-looking management strategies that are rooted in place and past.

1. Introduction

Climate change, land-use change, and other stressors are rapidly transforming ecosystems and landscapes across the globe, necessitating strategies for managing natural systems that foster biodiversity, provide key ecosystem functions and services, and are resilient to environmental change (Foley et al., 2005; Ellis et al., 2013; Grimm et al., 2013; Pecl et al., 2017). Equipping ecosystems to adapt to modern stressors requires consideration of future trajectories that account for variability and change in species, communities, and ecosystems over time (Hansen et al., 2010; Higgs et al., 2014). In this context, there is increasing recognition of the value of considering longer time horizons into the past in order to understand ecosystem conditions, dynamism, and response to environmental change over the time scales necessary for effective management (McClenachan et al., 2012; Gillson and Marchant, 2014; Barak et al., 2016).

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Historical ecology—that is, the reconstruction of past ecological patterns and dynamics (Rhemtulla and Mladenoff 2007; Beller et al., 2017)—can provide key information relevant to ecosystem conservation, restoration, and management (hereafter referred to as "ecosystem management"). Historical ecology research has long been used to establish baseline conditions and set restoration targets (Alagona et al., 2012) and to characterize ecosystem degradation (Swetnam et al., 1999). In addition, historical studies can serve as a "natural experiment" to study ecosystem response and resilience to past disturbances and climatic changes (Vellend et al., 2013; Nogués-Bravo et al., 2018), elucidate the natural range of variability of an ecosystem (Keane, 2009; Safford et al., 2012), identify persistent and novel sites or features in the contemporary landscape (Copes-Gerbitz et al., 2017), and provide information on lost or forgotten species or ecosystems that might serve as inspiration for current and future management, either in the same place or a location with an analog future climate (Grossinger et al., 2007). In many cases, surprising results and management recommendations emerging from historical ecology analyses have altered management priorities and strategies (McClenachan et al., 2015).

While historical ecology has clear application to ecosystem management, examination of these recommendations has remained at the case study level, and a systematic analysis of management recommendations coming from historical ecology literature is still lacking. This restricts our ability to analyze patterns across taxa, places, and systems and may also limit the accessibility of these recommendations for managers who might wish to take advantage of them. Therefore, we conducted a systematic review of published historical ecology studies from both terrestrial and aquatic habitats across the globe over the past 23 years to determine the types of ecosystem management recommendations emerging from the historical ecology literature and the degree to which these recommendations challenge the status quo. Our focus is the historical ecology literature (typically studies that reconstruct ecosystem dynamics at decadal or century timescales using primarily archival sources) rather than paleoecological studies (primarily studies that use fossils, pollen, sediment cores, and other records to reconstruct prehistoric ecosystem dynamics at geologic timescales; Dietl and Flessa, 2011; Barak et al., 2016). Though the two approaches are complementary and insights from a wide range of past time periods can yield important insights for management, paleoecology has received relatively more attention in the conservation literature (see for example Willis et al., 2010; Rick and Lockwood, 2013; Seddon et al., 2014; Barnosky et al., 2017). Characterizing ecological change over decades to centuries during the historical period is an important but often overlooked dimension of understanding current conditions and prioritizing management strategies (Dearing et al., 2015).

We address four primary questions: (1) What temporal and spatial scales, geographic and land-use contexts, ecosystem attributes, and types of sources characterize the management-oriented historical ecology literature? The few existing surveys of the historical ecology literature largely focus on broad overviews of the field (e.g., Szabó, 2015; Beller et al., 2017) or provide qualitative overviews of methods and techniques (e.g., Vellend et al., 2013); there is currently a dearth of understanding of where and how historical ecology studies have been conducted that would yield insights into patterns, strengths, and gaps in the field. (2) What recommendations for ecosystem management have emerged from the global body of historical ecology research? While such syntheses of management recommendations have been influential across other spheres of applied conservation (e.g., climate change adaptation, Heller and Zavaleta, 2009), there has been no systematic analysis of the recommendations generated by historical ecology studies, restricting our ability to analyze patterns across taxa, places, and systems. (3) To what extent do recommendations from historical ecological studies challenge status quo ecosystem management recommendations or practices in the study system? While individual case studies have been shown to often fundamentally alter management priorities and strategies (cf. McClenachan et al., 2015), the prevalence of surprising recommendations is unknown. (4) How do recommendations from historical ecology—a field adopting a long-term, past-oriented perspective—compare to recommendations generated from climate change adaptation research, where a long-term, future-oriented perspective is assumed? We focus on climate change given its importance as a global change driver and the importance in both historical ecology and climate change adaptation of thinking across broad time scales. Our aim with these four questions is to facilitate the integration of insights from historical ecology into the larger conversation surrounding ongoing and future ecosystem management.

2. Methods

2.1. Literature review and selection

In November 2017, we searched the Web of Science database for peer-reviewed journal articles that used archival sources (i.e., sources found in a museum, archive, or other repository; Pearce-Moses, 2005) to reconstruct historical ecological conditions and make recommendations for ecosystem restoration, conservation, and management. We developed a search term with four sets of linked criteria: (1) topical (i.e., paper addresses ecological history and/or change), (2) time period (i.e., paper addresses the historical period rather than prehistoric or geological timescales), (3) methodological (i.e., paper uses archival sources), and (4) application (i.e., paper mentions application to ecosystem management). Strings of search terms for each category were linked with the "AND" operator to identify candidate papers of interest (see Appendix A for full search terms). We did not include white papers, technical reports, or book chapters.

To be included, papers had to present empirical data and include at least one recommendation for ecosystem restoration, conservation, or management. In addition, papers must have used at least one type of archival source material (e.g., maps, textual data, aerial imagery, landscape photography, museum specimens; Fig. 1) dating from before 1940 to characterize historical ecological conditions or change (i.e., not other abiotic characteristics such as water quality, geomorphic change, or

Fig. 1. Examples of archival sources used by historical ecology studies. Common sources include maps (a, b); lithographs, drawings, and paintings (c), textual documents such as newspaper articles, diaries, field notebooks, and travelogues (d); resource surveys such as fisheries logbooks, land surveys, and timber surveys (e); and museum specimen collections (f). *(Courtesy of (a) The Bancroft Library, UC Berkeley; (b) U.S. Geological Survey; (c) Claremont Colleges Digital Library; (d) The Jepson Herbarium, UC Berkeley; (e)Yale Peabody Museum, and (f) the University of Iowa.).*

carbon). The year 1940 was chosen as a cutoff in order to focus on studies characterizing ecosystem dynamics before the major changes that followied World War II in many regions.

Following the PRISMA methodology (Preferred Reporting Items for Systematic Reviews and Meta-Analyses; Moher et al., 2009), we reviewed the titles of the records yielded by this search (n = 2449) to remove duplicates and exclude papers that did not meet the inclusion criteria (n = 1357). We then reviewed the abstracts and full text of the remaining candidate papers (n = 1092) to assess them for eligibility. Of these, 217 papers from 1994 to 2017 met the criteria for inclusion and were coded for use in this synthesis.

2.2. Paper coding and data analysis

To extract information from eligible papers, we created a database adapted from a similar effort that analyzed biodiversity conservation recommendations in the face of climate change (Heller and Zavaleta, 2009). We coded each study's contextual information, including geographic and temporal context (geographic location, land-use context, spatial scale, and time span covered by the study) and ecological focus (focal taxa, ecosystem types, and ecological questions addressed). We also coded methodological information, including the types of historical archival sources and ancillary, non-archival sources (e.g., satellite imagery, contemporary field data, archaeological reports, modeling/simulation) used by each study. We coded eight types of historical archival sources (see Table 1): maps, textual documents, resource surveys, field surveys, aerial photographs, landscape photographs, museum and specimen collections, and oral histories.

To analyze ecosystem management recommendations, we transcribed each recommendation as written by the study authors, then assigned them to recommendation categories. Management recommendation categories were modified from previous efforts (Heller and Zavaleta, 2009; McLaughlin et al., *in prep*), with additional categories specific to historical ecology added as needed during the coding process. There were 78 possible categories (Table 3); each paper could be coded into a maximum of four. For example, a recommendation to “create more open canopy and understory conditions…[via] prescribed fire, canopy gap creation, and understory thinning” (Fahey and Lorimer, 2014) was coded as both “Use prescribed fire” and “Decrease forest density.” Recommendations were only coded if they included a specific activity or action that could be taken by an ecosystem manager (e.g., “monitor”, “thin forest”, “increase connectivity”) or a general principle that could inform management actions (e.g., “restore within historical range of variability” or “manage at a landscape scale”). Recommendations for further research were not coded, nor were generic recommendations stating the value of history (e.g., “consider historical baselines”). Recommendations were tabulated across papers, then ranked by frequency to identify the most common recommendations across the global historical ecology literature. Finally, we aggregated these management recommendation

Table 1
Archival sources used by historical ecology studies.

Source	% of articles
Maps	38
Textual documents *(e.g., newspaper articles, diaries, logbooks)*	37
Land, property, and resource surveys *(e.g., timber surveys, fisheries surveys, land surveys)*	34
Aerial photographs	22
Ecological and scientific field surveys	20
Museum and specimen collections	12
Landscape photographs	8
Oral histories *(e.g., ethnographies and interviews from before 1940)*	7

types into 12 broader categories: for example, recommendations to focus efforts on a diversity of species, ecosystems, and genes/phenotypes were aggregated into an overall category of "protect/restore biodiversity." We used these 12 categories to identify key themes emerging across papers.

In addition, we coded whether a paper included recommendations that substantially revised or challenged the management status quo for the site or ecosystem in question, as reported by the authors. We also captured whether each paper mentioned ongoing or projected future climatic change, and whether the paper contained recommendations that addressed the potential effects of climate change. All data were analyzed in RStudio v.1.1.456.

3. Results and discussion

3.1. *Characterizing the management-oriented historical ecology literature*

In total, we recorded 649 management recommendations from 217 peer-reviewed papers (see Appendix B for full list of coded papers). Study area size was generally large: over three-quarters of papers that specified a spatial scale covered over 100 km^2; median spatial scale covered by paper study areas was 1046 km^2 (IQR 5423 km^2) (Fig. 2). Study time span was similarly long: nearly three-quarters of papers that specified a time span covered over 100 years; median time span covered by studies was 144 years (IQR 105 years) (Fig. 3). Study focus spanned ecological scales, from population- and species-level to ecosystem- and landscape-level studies (Fig. 4d). Ecosystem extent and loss/gain in land cover types, community composition and diversity, and population or species-level abundance or other characteristics (e.g., genotypic/phenotypic diversity or biomass) were each covered by over one-third of studies (42%, 37%, and 34% respectively).

Studies drew on a wide variety of archival source types, with historical maps, textual data, and resource surveys each used by over one-third of articles (Table 1). Over three-quarters of studies drew on only one or two sources types of the eight categories coded. In addition to historical archival sources, studies drew on ancillary source material to reconstruct

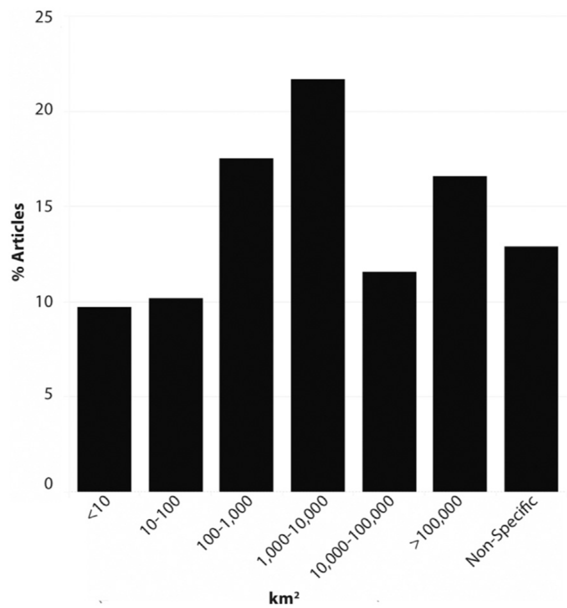

Fig. 2. Spatial scale of historical ecology papers coded.

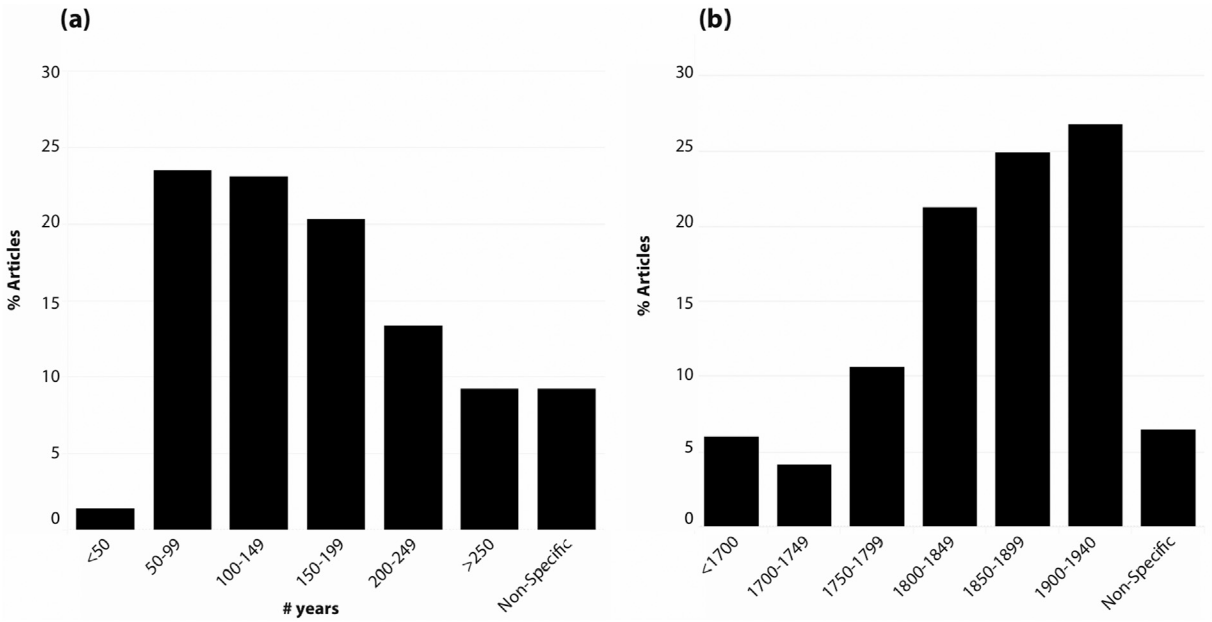

Fig. 3. Time span of historical ecology studies coded (a) and study start dates (b).

prehistoric or contemporary conditions, including field surveys and observations conducted as part of the study (32%), field surveys and observations conducted prior to the study (31%), and satellite imagery (24%).

The majority of historical ecology literature emerged from a few regions and ecosystems. Nearly 90% of studies were from the United States and Europe; only 6% focused on Africa, Asia, or Central/South America (Table 2). Terrestrial ecosystems and taxa were most represented, with forests in particular studied by nearly half (48%) of papers (Fig. 4a and b). Of papers that specified a contemporary land-use context, approximately two-thirds included a landscape characterized by human uses (e.g., urban area, cropland, or forestry), while only one-third of studies included a protected area (Fig. 4c).

3.2. *Management recommendation emerging from the global body of historical ecology research*

The conservation and restoration of former and/or native species, communities, and ecosystems was by far the most prevalent recommendation, found in 38% of all papers (Fig. 5). Other common recommendation categories included active management practices (e.g., prescribed fire and grazing management; 27% of papers), increasing connectivity (18% of papers), and protecting/restoring habitat remnants and areas of persistence (18% of articles). Here we highlight three key themes that emerged across studies: (1) the importance of both preserving habitat remnants and embracing the ecological values of human modified ecosystems, (2) the role of people in shaping and stewarding ecosystems, and (3) the value of managing across scales.

3.2.1. *Preserving habitat remnants and embracing modified ecosystems*

Studies that used historical data to identify habitat remnants and make recommendations to protect existing remnants and prioritize conservation around them were prevalent. Habitat remnants were seen as having high conservation value given their rarity, biodiversity, ability to act as plant source populations for disturbed areas or newly restored habitat, and role in facilitating wildlife movement across the landscape. In native prairies in Oregon, for example, Duren et al. (2012) found vegetation conversion over the past ca. 150 years to be concentrated in valleys, and recommended that conservation of these low-lying remnant native prairie vegetation be a high priority. In woodland and forest ecosystems, individual old and/or large trees were frequently identified and recommended for increased conservation priority given their rarity in many contemporary landscapes, the difficulty of replacement, and their potential to support biodiversity (e.g., Jönsson et al., 2009; Sanchez-Meador et al., 2010; Plienenger, 2012; Lydersen et al., 2013).

Prioritizing restoration and conservation actions in areas around existing remnants was also frequently recommended. In Germany, for example, Wulf et al. (2017) identified areas where deciduous forest had been preserved over 230 years despite overall trends in conversion to coniferous forest, and recommended integration of these “near-natural” stands into restoration projects to facilitate plant colonization into newly restored areas. Remnants were also used to identify sites where habitat persistence over long time scales was indicative of resilience to disturbance or opportunities to take advantage of persistent abiotic conditions or processes. For example, Beller et al. (2016) demonstrated that historical heterogeneity in riparian habitats along a river in southern California, U.S., was driven by persistent geophysical controls on groundwater and

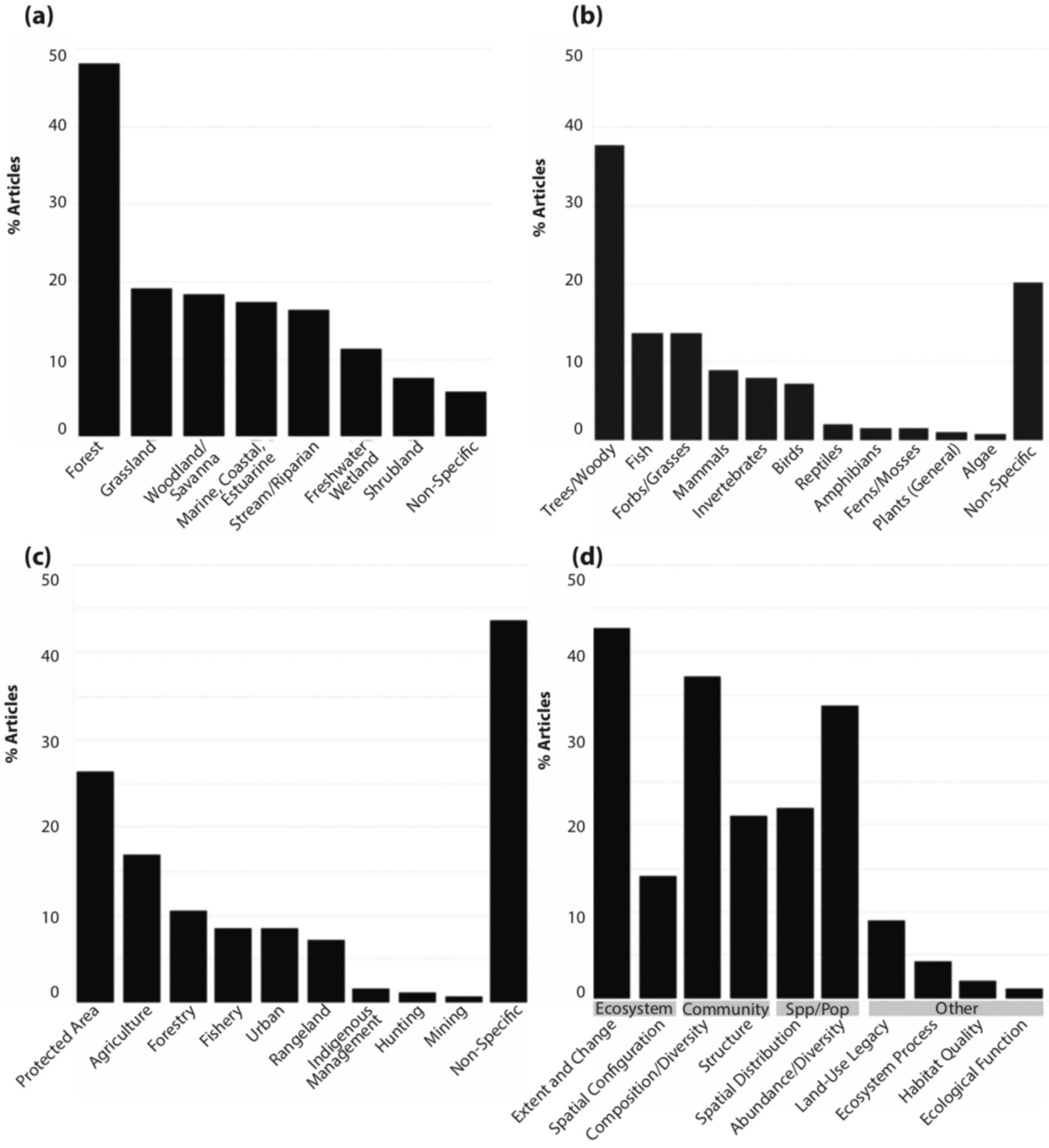

Fig. 4. The ecosystem type (a), taxa (b), land use context (c), and ecological study focus (d) of historical ecology papers coded.

surface flow, and used remnant habitats to identify promising areas for riparian restoration where supported by abiotic conditions.

While recommendations to preserve and restore around habitat remnants were prevalent, other recommendations embraced human modifications of the landscape by highlighting the importance of actions in highly modified landscapes and identifying new ecological values of such landscapes. In the city of San Jose, U.S., for example, Whipple et al. (2011) estimated near-complete declines in native oak populations and recommended using historical landscape patterns to re-introduce oaks in an urban context. In an agricultural setting, Grixti et al. (2009) quantified decreases in bumblebees in Illinois, U.S., coincident with 20th century agricultural intensification and recommended wildlife-friendly agricultural practices such as interspersed habitat patches and hedgerows to counteract this decline. Blixt et al. (2015) found that clear-cuts in Sweden on former grasslands supported butterfly species, suggesting the importance of conserving these highly modified habitats as

Table 2
Geographic setting of historical ecology studies. Each paper was coded with up to two study regions (total is therefore greater than the number of studies).

Study Region	# articles
Africa	6
Asia	6
Central/South America	7
Europe	
Eastern	*17*
Northern	*18*
Southern	*15*
Western and British Isles	*35*
General	*3*
North America	
Canada	*17*
Mexico	*3*
Caribbean	*4*
U.S. - Mid-Atlantic	*1*
U.S. - Midwest	*17*
U.S. - Mountain West	*4*
U.S. - Northeast	*12*
U.S. - Pacific West	*29*
U.S. - Southeast	*7*
U.S. - Southwest	*10*
General	*2*
Other	
Arctic	*1*
Australia	*7*
New Zealand	*3*
South Pacific Islands	*1*
Multiple (synthesis paper)	*4*

part of the overall landscape mosaic. A study on the spread of the invasive shrub *Lantana camara* across Australia, India, and South Africa (Bhagwat et al., 2012) found that extensive measures to control and eradicate the species over the past 200 years have been largely unsuccessful, and suggested acceptance of the novel ecosystems created by the invasion rather than attempting eradication. Other examples include the use of mining spoil heaps as restoration sites in the Czech Republic (Hendrychova and Kabrna, 2016) and the creation of artificial wetlands in Israel to complement protection and restoration of remnant habitats and offset the loss of historical wetlands (Levin et al., 2009). Studies also suggested the conservation and restoration of “intermediate” habitats where they support biodiversity, such as semi-natural grasslands grazed by livestock in Sweden that support grassland plant species (Gustavsson et al., 2007) and second-growth forests in California that protect old-growth forest stands from edge effects (Fritschle, 2012).

3.2.2. *Recognize ecosystems as cultural landscapes*

While a historical perspective is sometimes characterized as a focus on “pristine” or “wild” conditions, historical ecologists have long recognized the legacies of human modification and stewardship of ecosystems and landscapes (Berkes, 2004; Jackson and Hobbs, 2009). The historical role of humans in shaping landscapes was reflected in management recommendations: in aggregate, management via traditional interventions such as mowing, grazing, fire, and pruning was the second most highly ranked recommendation category, endorsed by 27% of studies. Often, the recommended approaches preserved or mimicked traditional or past landscape stewardship practices, acknowledging the influence of previous land use management regimes on current ecosystem characteristics. For example, Jurskis (2011) demonstrated the lack of fallen timber historically in Australian grassy woodlands due to Aboriginal fire management, and recommended the reintroduction of practices such as broadcast burning and firewood collection to restore habitat heterogeneity and rare species. Recommendations are not restricted to traditional indigenous practices: in the sand-plain woodlands of Massachusetts, U.S., for example, Eberhardt et al. (2003) demonstrated the role of past agriculture in creating heathland and grassland communities and suggested mimicking agricultural practices to restore these habitat types. Recommendations also identified the importance of conserving cultural landscapes. For example, McCune et al. (2013) showed that indigenous management maintained Garry oak ecosystems in British Columbia, Canada, and recommended prioritizing such these landscapes for conservation. Additional recommendations included incorporation of Traditional Ecological Knowledge or other sources of local environmental knowledge into ecosystem management activities (e.g., MacDougall et al., 2004; Kurashima et al., 2017).

3.2.3. *Consider landscape context and site-scale differences*

The value of a landscape-scale perspective is emphasized by the historical ecology literature, where long temporal scales of investigation are often accompanied by large spatial scales. Studies emphasized the value of a large-scale perspective to

Table 3
List of recommendations for ecosystem management, synthesized from peer-reviewed historical ecology articles and ranked by frequency. All categories recommended by >5% of papers are listed here.

Rank	Recommendation	# articles	References (*see Appendix B*)
1	Protect/restore former and/or native species, communities, and ecosystems	60	2, 3, 11, 17, 27, 33, 34, 35, 37, 38, 39, 41, 48, 50, 51, 52, 54, 61, 68, 70, 71, 72, 76, 80, 82, 88, 95, 101, 106, 109, 114, 130, 132, 133, 138, 142, 143, 144, 146, 147, 150, 152, 153, 161, 167, 169, 178, 181, 185, 188, 189, 192, 196, 198, 200, 201, 214, 215, 216, 217
2	Increase connectivity	28	2, 6, 13, 16, 38, 43, 46, 47, 55, 67, 68, 86, 87, 104, 109, 114, 115, 128, 129, 130, 144, 152, 169, 171, 186, 207, 211, 214
3	Silviculture: decrease forest density or don't thicken (e.g., through removal of trees, snags, stumps; thinning, cutting, firewood collection, weeding)	26	7, 21, 23, 32, 50, 51, 71, 75, 80, 95, 108, 112, 113, 117, 118, 119, 130, 135, 137, 148, 149, 152, 179, 183, 193, 194
4	Address direct anthropogenic stressors to ecosystems (e.g., fishing, trawling, dredging, pollution, nutrient loading)	22	1, 5, 14, 64, 72, 78, 79, 96, 106, 121, 125, 131, 132, 133, 134, 139, 146, 150, 157, 160, 164, 196
5	Protect/restore biological structure (age, size, spatial patterns)	21	7, 8, 16, 23, 85, 95, 96, 114, 117, 118, 130, 135, 161, 163, 183, 184, 193, 194, 205, 207, 211
6	Maintain/restore grazing	20	6, 22, 27, 32, 45, 51, 60, 62, 81, 87, 89, 92, 104, 108, 109, 148, 149, 167, 182, 206
7	Employ prescribed fire	19	7, 21, 26, 44, 62, 71, 80, 89, 96, 112, 113, 117, 118, 137, 148, 152, 161, 194, 195
7	Adopt regional perspective, manage at a landscape scale, manage across scales or jurisdictions	19	1, 6, 22, 37, 67, 78, 83, 102, 104, 116, 132, 138, 143, 147, 156, 165, 183, 187, 201
7	Protect/restore biological heterogeneity and complexity	19	8, 23, 31, 70, 81, 83, 93, 94, 96, 104, 117, 135, 137, 152, 162, 173, 180, 183, 205
8	Protect/restore species diversity	18	8, 46, 47, 61, 69, 87, 89, 92, 119, 131, 146, 149, 154, 158, 170, 171, 173, 202
9	Reintroduce species (within range)	17	15, 23, 37, 49, 50, 51, 73, 74, 104, 106, 111, 154, 161, 173, 174, 196, 200
9	Create/enhance protected areas	17	2, 9, 11, 13, 18, 28, 32, 61, 64, 67, 68, 72, 102, 106, 131, 132, 209
9	Practice monitoring (e.g., of key species or populations, of efficacy of restoration efforts)	17	10, 11, 36, 55, 65, 70, 77, 79, 84, 137, 148, 160, 168, 189, 190, 208, 213
9	Protect/restore habitat remnants and fragments	17	6, 28, 59, 73, 75, 88, 91, 109, 121, 128, 140, 157, 168, 171, 177, 195, 212
10	Protect/restore environmental setting, abiotic conditions and processes	15	13, 27, 29, 30, 55, 72, 87, 164, 166, 176, 180, 188, 189, 207, 214
11	Protect/restore uncommon, endangered, rare, or underrepresented species, communities, and ecosystems	14	7, 13, 50, 56, 59, 69, 75, 91, 97, 123, 124, 127, 192, 195
12	Manage at a site scale, consider different approaches for different areas based on land-use history or environmental context	13	12, 13, 20, 59, 81, 88, 91, 108, 130, 142, 178, 180, 187
13	Protect/restore diversity of habitat or ecosystem types	12	2, 22, 59, 90, 91, 95, 148, 155, 166, 171, 187, 192
13	Protect/restore around areas of persistence (e.g., around habitat remnants, in areas of persistence of geophysical conditions)	12	6, 13, 68, 76, 80, 92, 100, 101, 119, 159, 192, 216
14	Protect/restore ecosystem function or process	11	21, 28, 60, 66, 81, 84, 89, 84, 104, 147, 148
14	Protect/restore matrix habitats + human-dominated landscapes − agriculture	11	45, 47, 53, 82, 90, 114, 145, 158, 166, 168, 178
14	Protect/restore old, large trees	11	8, 94, 104, 110, 135, 170, 172, 183, 191, 211, 212
14	Protect/restore novel/no-analog species, communities, and ecosystems	11	19, 22, 43, 81, 84, 99, 106, 124, 128, 130, 195
14	Recognize human-environment interactions, cultural nature of landscapes, influence of land-use history on ecology	11	4, 20, 21, 43, 62, 92, 104, 112, 141, 149, 209

enable cross-sector coordination and collaboration across stakeholders and jurisdictions; characterize abiotic gradients, processes, and heterogeneity; and identify and prioritize opportunities to improve connectivity, biodiversity, and other factors across the landscape. The importance of considering landscape context is similarly increasingly recognized in the broader ecosystem management literature (cf. Menz et al., 2012; Hobbs et al., 2017).

For example, in Iowa, U.S., Gallant et al. (2011) used 19th century federal land surveys coupled with modern inventories of wetlands and hydric soils to show dramatic wetland losses across the state, and recommended adoption of landscape-scale perspective on ecosystem change to capture the full range of historical wetland extent and diversity, understand the dramatic transformations of the past centuries, and identify locations most likely to support wetland complexes in the future. The integration of terrestrial and aquatic ecosystem management was also recommended by a number of studies. In the Columbia River Basin in the U.S. Pacific Northwest, for example, Hessburg et al. (2000) characterized changes in forest vulnerability to disturbances such as wildfire and insects; they stressed the influence of upland disturbances on aquatic ecosystem health and recommended the joint consideration of restoration strategies for aquatic and forest habitats. In the marine realm, the synthesis of multiple drivers of oyster decline over more than a century in Scotland led Thurstan et al. (2013) to recommend integrated management of terrestrial and marine impacts on nearshore ecosystems.

The large spatial scales adopted by many studies also generated insights into between-site differences often obscured in site-scale studies. As a consequence, many studies stressed the importance of using different management approaches for

Fig. 5. Top ten recommendations for ecosystem management generated by the historical ecology literature, aggregated by overall category (e.g., genetic/phenotypic diversity, species diversity, and ecosystem diversity are lumped into "biodiversity"). Examples provided in the right column of this figure are the more granular recommendations as coded and listed in Table 3.

areas with divergent land-use histories or abiotic conditions, even if they appear superficially similar, and cautioned against generic "one size fits all" approaches (e.g., Bieling et al., 2013; Fuller et al., 2017). For example, in a study of land-cover change on the French coast, Godet and Thomas (2013) distinguished three types of grasslands in the contemporary landscape based on land-use history and recommended different management pathways for each type. In a desert landscape in New Mexico, Browning et al. (2012) found that soil water holding capacity controlled shrub response to disturbance, and recommended prioritizing grassland restoration on sites with higher near-surface water holding capacity rather than sites with coarse-textured soils in order to maximize their resilience to drought.

3.3. Challenges to status quo management practices

Historical ecology has been recognized for its ability to provide new insights that can adjust how we manage species and ecosystems (e.g., Walter and Merritts, 2008; McClenachan et al., 2012. McClenachan et al., 2015). Our study affirms this:

nearly one-quarter (23%) of studies contained at least one recommendation that authors explicitly stated revised or challenged status quo management activities. The prevalence of such recommendations emphasizes the value of a historical perspective in shifting our understanding of desirable management goals, strategies, and targets. It also underscores that even "conventional" past-oriented recommendations—for example, to restore former ecosystem conditions—may run counter to current management practices by providing a revised understanding of former conditions.

Studies employed a historical perspective to identify previously unrecognized species, ecosystems, or sites for management. For example, in northern California Grossinger et al. (2007) found evidence of sycamore-alluvial woodland riparian habitats on stream reaches now dominated by dense cottonwood forests, and recommended restoration of these habitats given their rarity and tolerance to drought. Plumeridge and Roberts (2017) reconstructed large declines in fish communities off the coast of England and emphasized the importance of considering rare or extirpated fish as conservation targets that have long been ignored given their lack of economic importance. In southern California, Stein et al. (2010) demonstrated a nearly 90% loss of wetlands since the 19th century and noted that the formerly most widespread wetland types were the most impacted by development yet were rarely included in restoration planning efforts, despite opportunities for recovery where supported by persistent groundwater conditions. In some cases, findings were used to identify new locations for conservation. For example, Ferretti et al.'s (2016) reconstruction of sawfish biogeography and extinction in the Mediterranean Sea over ~400 years broadened the species' historical range and suggested previously unidentified sites for sawfish reintroductions.

Studies also questioned or revised existing assumptions about management targets for the species and ecosystem type, population abundance, and community structure appropriate for a given location. For example, Bukowski and Baker (2013) cautioned against current proposals to remove trees encroaching into sagebrush across a four-state region in the western United States, noting that trees naturally occurred in sagebrush habitats and that their removal would not be ecological restoration. In California's Sierra Nevada mountains, Stephens et al. (2015) found increases in canopy cover over the past century and concluded that current goals for restoring forest canopy cover should be revised downward to reflect historical density estimates and increase the resilience of forest ecosystems to future disturbance. An investigation of Sooty Tern population declines on Ascension Island in the south Atlantic Ocean demonstrated an 84% decline in population size over three generations of the species and suggested upgrading the species' conservation status to "Critically Endangered" (Hughes et al., 2017).

3.4. Looking back, looking forward: historical ecology and climate change

Fifty-seven papers (26%) mentioned the potential impacts of climate change on their study system such as changes in temperature (15 papers) and drought (11 papers). Of these, 25 papers (<12% of all papers coded) contained at least one recommendation that explicitly addressed a dimension of ongoing or projected climate change. Recommendations included both traditional and explicitly future-oriented strategies, including protecting and restoring biological structure and heterogeneity (e.g., Lydersen et al., 2013; Tucker et al., 2016) and native species and ecosystems (e.g., Clavero et al., 2017); restoring abiotic environmental conditions and processes and prioritizing restoration where supported by these conditions (e.g., Paalvast and van der Velde, 2014), and targeting areas likely to provide suitable habitat in the future (e.g., Danneyrolles et al., 2017).

The question of how to prioritize ecosystem management activities in the context of climate change has received increasing attention over the past decade, with a number of reviews aimed at helping guide ecosystem management (e.g., Mawdsley et al., 2009; Heller and Zavaleta, 2009; Lawler, 2009; Hansen et al., 2010; Stein et al., 2013). While our focus here is broader (i.e., on general ecosystem management rather than climate change adaptation), many of the approaches prevalent in historical ecology studies are also emphasized by the climate change adaptation literature. This is particularly true of landscape- and ecosystem-scale recommendations, such as increasing connectivity, expanding protected areas, mitigating or reducing non-climate stresses to ecosystems, and adaptive management and monitoring (see Appendix C for additional detail).

While there is substantial overlap in recommendations between the two bodies of literature, there are also apparent points of divergence (Fig. 6). Some approaches gaining prevalence in the climate change adaptation sphere, based on a recent analysis of recommendations (McLaughlin et al., *in prep*), are rare or absent in the historical ecology literature. These include explicitly future-oriented approaches such as translocation beyond the species' current range (e.g., Adams-Hosking et al., 2015; Şekercioğlu et al., 2012), targeting genotypes adapted to future conditions (e.g., Li et al., 2014; Zheng et al., 2015), and protecting genotypic and phenotypic diversity (e.g., Gray et al., 2014; Abbott et al., 2017). Many of the approaches least well represented by the historical ecology literature are at the species or population level, perhaps reflecting the large spatial scales of many studies and the challenge of obtaining historical data at smaller ecological scales. Conversely, emphases in historical ecology such as protecting and restoring around habitat remnants, protecting abiotic conditions and processes, and human stewardship of ecosystems (e.g., via traditional management practices) are less well represented in the climate change adaptation literature.

4. Conclusion

Here we present the first quantitative analysis of the global historical ecology literature across ecosystems, with a focus on the management recommendations generated by this body of research. Perhaps not surprisingly, many of the most common

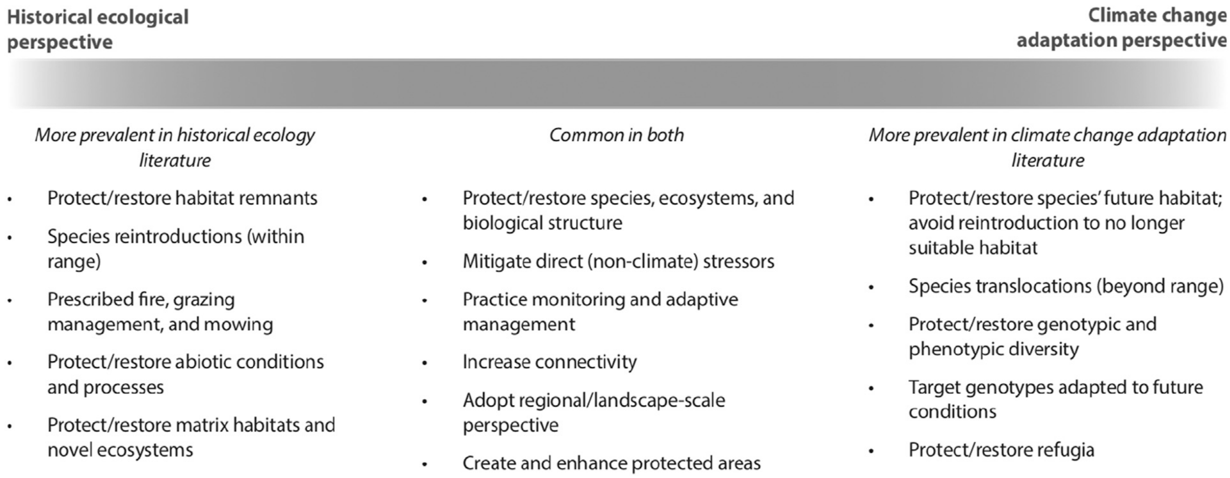

Fig. 6. Conceptual comparison of example recommendations prevalent in the historical ecology literature (left, from current study), climate change adaptation literature (right), and in the top ten recommendations of both (center). Comparison is based on this paper plus synthesis of a number of reviews of the climate change adaptation literature (cf. Heller and Zavaleta, 2009; Lawler et al., 2009; Mawdsley et al., 2009; Hansen et al., 2010; Groves et al., 2012; Stein et al., 2013, and McLaughlin et al., in prep).

recommendations were associated with preserving or recovering former conditions or functions, such as protecting habitat remnants or reintroducing species within their former ranges. However, papers also made a range of other recommendations including the importance of ecosystem management in highly modified and human-dominated ecosystems, prioritizing people in landscape stewardship, and taking a larger, landscape-scale perspective. In addition, a substantial number of studies contained surprising recommendations that challenged status quo management. These results suggest that the broad temporal—and frequently spatial—scales adopted by historical ecology studies, coupled with a unique set of sources and approaches, equips the historical ecologist with a distinct perspective that can be challenging to acquire from short-term ecological studies and can be conducive to spurring new ideas and insights about ecosystem characteristics, processes, and potential.

A focus on the past is sometimes framed as standing in contrast or opposition to future-oriented management. “Backward looking” goals are cast as a desire to return to former ecosystem states, increase ecological integrity, and resist change, while “forward looking” goals are focused on restoring functions, increasing resilience to change, and embracing novelty (e.g., Seastedt et al., 2008; Heller and Hobbs, 2014; Miller and Bestelmeyer, 2016). We believe that this is a false dichotomy. Recommendations in the historical ecology literature are generally aligned with those fields such as climate change adaptation more traditionally conceived of as “forward looking.” Far from aiming to restore a stable or pristine wilderness, historical ecology provides insights that cultivate a sense of ecosystems in their specific social and environmental contexts, and emphasizes the importance of people—now and in the past—in shaping and stewarding the natural world. It emphasizes the importance of habitat fragments and other areas of persistence, not as a return to the past, but as repositories of biodiversity and resilience, often linked to relatively stable abiotic conditions and processes. And it accentuates that historical and novel ecosystems are not two ends of a spectrum, as commonly portrayed, but occur side by side in complex, hybrid landscape mosaics superimposed at a variety of scales (cf. Hobbs et al., 2014).

That said, there are also clear directions for future research in historical ecology to enhance the field's applicability and representativeness. Our findings underscore key research gaps, in particular the paucity of studies focused on Asia, Central/South America, and Africa. In addition, we highlight the relative lack of research on aquatic ecosystems. The predominance of studies analyzing forests undoubtedly influenced recommendation rank; additional research could help provide more ecosystem-specific insights about the types of strategies and actions recommended.

Our research also suggests several opportunities for further synthetic research of the historical ecology literature. First, while we only examined journal articles available through Web of Science in the present study, additional valuable analyses are available in government documents, monographs, book chapters, and reports; inclusion of these studies would enhance understanding of the recommendations emerging from historical ecology. Second, it is unclear how the characteristics of papers that include explicit recommendations for management compare to the broader body of historical ecology literature (many of which do not include recommendations); future research could elucidate how the articles reviewed here related to the broader field in terms of study spatial and temporal scale, ecosystem and geographic context, and other dimensions. Third, it is unknown how these results would differ from a random sampling of management recommendations from conservation-focused papers from the same time frame; a next step would be to compare recommendations from the historical ecology and broader field of conservation to assess differences in the type and prevalence of recommendations from the two bodies of literature. Finally, it would be valuable to catalog the key system attributes quantified across historical ecology studies that have been used to identify management recommendations; this would provide insight into the types of historical information most useful and relevant for ecosystem management.

Our results also suggest an opportunity for historical ecology to more explicitly address environmental change. While many of the historically informed management strategies and targets suggested in the literature are likely to be appropriate in the future, there is no guarantee that this will be the case, and historical ecologists should be encouraged to explicitly address future changes in climate and disturbance regimes and explore the potential impact on appropriate management approaches. Fundamentally, however, we stress that insights generated from historical perspective are an essential component of developing future-oriented approaches to ecosystem management: approaches that are dynamic, creative, and novel yet rooted in place and past.

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Appendices. Supplementary data

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