Global decline in subsistence-oriented and smallholder fire use

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Abstract

Controlled fire use by hunter-gatherers and smallholder agriculturalists and pastoralists shapes ecologies and enhances livelihoods worldwide. Yet, at the global scale, we know little about how these practices influence human wellbeing, ecologies, and wildfire risk. As a basis for global syntheses, we collated information from the literature about fire practices in 587 case study locations spanning the globe. Here, we assess the coverage and completeness of this data. Limited quantitative data, particularly, presents a challenge for improved modelling of anthropogenic influences on fire regimes. We also analyse global trends in fire practices from these studies, finding evidence that subsistence-oriented fire practices have declined in recent decades, while market-oriented fire practices have increased. The case studies point to important drivers of these changes, especially economic pressures, and state governance. We discuss the implications of these findings for fire policy, and future research.

Introduction

Worldwide, controlled fire use is culturally and economically significant across human societies for subsistence-oriented or smallholder livelihoods, including hunting and gathering, pastoralism and agriculture[1]. These fire practices often draw on deep, place-based knowledge of the feedbacks between fire and its biophysical and social environment[2]. Beyond immediate livelihood benefits that structure the application of anthropogenic fire to landscapes, such fires have co-benefits. People tend to make small, frequent fires that produce a more heterogenous landscape, supporting greater biodiversity and fragmenting fuels, which reduces wildfire risk[3,4]. Simultaneously, especially in changing climates and environments, or where local governance institutions and fire knowledge are being lost, anthropogenic fire can potentially lead to uncontrolled wildfires, posing risks to human health and wellbeing[1]. Generally, such wildfire events dominate public and policy discourse around fire[5], not the social and ecological relevance of controlled fire use.

Recent global studies demonstrate that annual burned area has decreased in recent decades[6], while extreme wildfire events are becoming more frequent and intense[6,7,8]. Drivers of these trends include fragmentation of fuel landscapes with land use change, accumulation of flammable vegetation after suppression of human fire use, and lengthening fire weather windows due to climate change[9,10]. In this context we need to better understand the conditions under which the loss of livelihood-oriented fire use can lead to wildfires. Since the 1990s, a growing number of case studies have examined local fire knowledge and practices, but with limited synthesis of this literature at the global scale[1]. Existing literature reviews have drawn on few sources, have often been biased geographically towards North America and Australia, and examined narrow research questions[2,4,11,12,13,14]. We do not adequately understand the social conditions in which smallholder and subsistence livelihood-oriented fire use is currently changing, nor the implications for fire ecologies, human wellbeing, and wildfire events[15]. Most global fire models represent human fire use and suppression as a function of variables such as population density or Gross Domestic Product (GDP), failing to account for different ways in which people use fire, or how this varies across environmental and social contexts[16.] Similar variables are used to make inferences about the human signal in global fire remote sensing studies[6,17].

To build an empirical basis for studying livelihood-oriented fire practices at the global scale, we conducted a systematic review of 592 published and unpublished sources to create an open-source database, the Livelihood Fire Database (LIFE), describing 1708 contemporary subsistence-oriented and smallholder fire use and mitigation practices in 587 case study locations. LIFE contains data on both social and biophysical aspects of fire practices. This resource can support, for example, future analyses covering the spatiotemporal patterns of fires set for diverse livelihood purposes, different forms of fire governance, and drivers of change in fire practices. Here, we assess the coverage and completeness of the LIFE database, present a typology of fire use purposes developed from the database, and assess contemporary trends in these fire practices.

Results and discussion

The LIFE database demonstrates that fire use and mitigation practices have remained important within subsistence-oriented and smallholder livelihoods worldwide over the past 30 years. Yet, subsistence-oriented fire practices have declined at the global scale, while market-oriented fire practices have increased. The following sections speak to these findings in turn, and discuss their implications for human wellbeing, ecologies, and wildfire risk. Finally, we reflect on gaps in our knowledge of these fire practices as highlighted by LIFE, and implications for future research and fire policies.

Fire practices contribute to diverse livelihoods worldwide.

LIFE contains information about 1708 fire practices, of which 92 percent were actively practiced at the time of the case study research and eight percent had been lost but were practiced within the living memory of research participants. 95 percent of practices in LIFE are examples of fire use. For 23 percent of these fire use practices, we have information about associated fire control measures.

One percent of practices in LIFE are examples of 'opportunistic' use of fires or burned areas created by lightning or other people. The remaining three percent of practices are general fire mitigation measures taken independently of fire use, including fire prevention and suppression practices. Our focus here is largely on fire use, but there is need for future research addressing fire control and mitigation specifically.

These practices were recorded for case study locations spanning 84 countries across all flammable continents, with the most locations in Brazil, Indonesia, Australia, Mexico, and India (Fig. 1). The USA, Canada, Australia, and China have the highest number of practices that were lost at the time of the case study research. Research biases shape the distribution of case studies to some extent. The high number of cases in Australia and the USA, for example, is probably more reflective of a bias towards research in these countries than it is of widespread contemporary subsistence-oriented and smallholder fire practices. Conversely, the low number of cases in eastern Europe and northern, western, and central Asia probably reflects lack of research rather than lack of fire practices. Despite research biases, the high concentration of cases in the equatorial tropics likely reflects a high prevalence of subsistence-oriented and smallholder fire practices in these regions.

The fire practices in LIFE contribute to livelihoods on a spectrum between subsistence-oriented and market-oriented. 43 percent of fire practices in LIFE are subsistence-oriented (associated with a product produced, gathered, or hunted mainly for subsistence), 15 percent are market-oriented (associated with a product produced, gathered, or hunted mainly for sale), two percent are practices that are themselves marketed as a service, and 20 percent are neither associated with markets or subsistence.

Using LIFE, we developed a hierarchical fire use purpose classification system including eight higher tier categories: agriculture, pastoralism, hunting and fishing, gathering, charcoal and firewood production, movement, human health and wellbeing, and social signals. Each of these higher tier categories is associated with several of 29 lower tier categories (Table 1). This scheme aligns broadly with, but is more detailed than, those developed in previous studies[4,12,18]. Our lower tier categories include both direct reasons for fire use, such as driving game for hunting or clearing vegetation for swidden agriculture, as well as co-benefits, such as reducing fuel loads or maintaining cultural identity. It is likely that many anthropogenic fires, especially those set in tropical savannas, are associated with multiple purposes, including proximate reasons and co-benefits[19]. We listed multiple purposes against a fire practice only where a source explicitly stated that multiple reasons were associated with the same ignitions (in 17 percent of cases). It is probable that a higher proportion of anthropogenic fires are associated with multiple purposes. Most sources analysed did not distinguish between direct reasons for fire use and co-benefits, so we could not make this distinction in LIFE. This is a limitation for future analyses, in that it is the more proximate reasons that are more likely to sustain fire use and consciously shape how fire is applied to the landscape[20].

Subsistence-oriented fire practices are declining globally.

We recorded trends in the proportion of the population in the study area practising the practice, the overall proportion of the study area affected by the practice annually, and the frequency with which the practice takes place in each affected landscape patch. Practices associated with two thirds of our 29 fire use purposes were significantly more likely to show decreasing trends in at least one of the variables in a two-tailed binomial test (Table 2). Except for pre- and post-harvest crop residue burning, for those fire purpose types for which we had insignificant results in the binomial tests, we had very small sample sizes ($n < 15$).

Declining trends in fire use have a historical precedent. From the 15th century, European colonialism, development of capitalist economies and intensification of agriculture directly and indirectly suppressed fire use associated with subsistence and smallholder livelihoods worldwide[21,22,23]. The LIFE database sheds light on contemporary drivers of changes in fire use. Subsistence-oriented fire use practices in LIFE are significantly more likely to show decreasing trends, while market-oriented fire use practices are more likely to show increasing trends in all three variables (Fig. 4). This suggests that economic pressures are a global driver of changing fire use.

Case studies in LIFE illustrate some of the mechanisms by which economic pressures are driving decreasing subsistence-oriented fire use. Sometimes, commercial land uses limit the land available to populations with subsistence-oriented livelihoods. In the Brazilian *cerrado,* for instance, expansion of industrial-scale capitalised agriculture is driving Indigenous and traditional populations into smaller territories, limiting fire use associated with hunting and gathering[24]. Elsewhere, market-oriented activities are replacing subsistence-oriented activities within livelihoods, reducing subsistence-oriented fire use. For example, in Guinea-Bissau, structural adjustment policies in the late 1980s created new export markets for cashew, driving smallholders to clear land for cashew orchards in following decades[25]. Adoption of the cashew cash crop has driven declines in swidden and savanna fire use because farmers have less time and land available for more traditional land uses, and they are wary of the risks of wildfire damage to their cash crops. Deepening capitalist relations also see the replacement of subsistence activities with wage labour and purchased goods. For example, in Australia, many Aboriginal people now live and work in large settlements 'off-country', decreasing their use of fire for hunting and gathering[26]. Notably, the substitution of market-oriented production or wage labour for subsistence livelihoods may only be partial. For Maya people in southern Belize, for instance, the insecurity and seasonality of labour and cash crop markets means that swidden agriculture remains important within diversified livelihoods[27].

State governance can be another direct or indirect driver of decreasing fire use. Over recent centuries, a narrative that fire use was incompatible with 'rational' land use was used as justification for policies aiming to eradicate anthropogenic fire in many countries, especially in European colonies[21,22,23]. Though many nation states have since adopted 'prescribed fire' (the controlled application of fire for specific land management objectives), this is usually solely deemed the prerogative of specialised agencies, while livelihood-oriented fire use is heavily regulated. For instance, in the Borana rangelands of Ethiopia, pastoral fire use has largely been lost after enforcement of a general ban on fire use[28]. Fire regulations may be specific to, or only see enforcement in, protected areas such as the Biligiri Rangaswamy Temple Tiger Reserve in India, where Soliga people have stopped practising customary fire use since it was made illegal[29]. Regulations may also impose restrictive conditionality upon fire use. In Laos, laws that severely limit the amount of land allocated to each household and restrict fallow periods to 5 years have made it difficult to maintain swidden agriculture[30]. Many countries have strong anti-fire regulations, but it is important to note that these are not always enforced: it is often easy for fire users to remain anonymous; states may lack the resources for strong enforcement; and those state officials responsible for enforcement may collude with fire users[22,31,32].

Besides regulation, economic governance mechanisms are driving declines in fire use. In recent decades one such mechanism has been Payments for Ecosystem Services (PES) schemes, where these have made payments conditional upon eliminating fire use. For instance, in the *páramos* of Ecuador, communities participating in the Socioparamo PES scheme are paid to cease burning and grazing in certain areas[33]. Elsewhere, such as in Mexico, agricultural subsidies from the Government have only been available for permanent agriculture rather than swidden, and grants have supported the adoption of agrochemicals and mechanical tillage, which replace fire use[34].

Case studies in LIFE highlight potential implications of declines in or loss of subsistence-oriented fire use. Declining fire use can severely undermine the livelihoods of rural people. For example, for

Borana pastoralists in Ethiopia, loss of fire use in rangelands has led to bush encroachment and forage scarcity[28], and prohibition of fire use has reduced household income from agriculture and forest produce for Soliga people in India[29]. Sometimes, as for some Pemón communities in Venezuela, declining fire use can lead to a loss of cultural identity and conflict between older generations who retain fire knowledge and younger generations who are losing this knowledge[35]. Notably, its association with cultural identity may also contribute to the persistence of fire use in the face of countervailing drivers, as with the swidden agriculture of Tagbanua people in the Philippines[36].

Loss of human fire can reduce the biodiversity of fire-dependent ecosystems. In the Biligiri Rangaswamy Temple Tiger Reserve in India, loss of Soliga fire use has increased vegetation density to the point of suppressing the growth and recruitment of many tree and plant species[29]. Meanwhile, in Australia, hill kangaroos are more abundant in regions with fine-grained vegetation mosaics resulting from Martu hunting fires, than in regions dominated by lightning fire[37]. Loss of smallholder and subsistence-oriented fire use can also lead to increased wildfire risk where it leads to more homogenous fuel landscapes. Case studies in LIFE suggest that fire use associated with reducing fuel loads at the landscape scale, or creating firebreaks is declining. In the Brazilian *cerrado*, Indigenous Reserves where Xavante fire use for hunting and gathering is retained suffer significantly less wildfires than reserves where fire use has been lost or has declined[24]. When fire use reduces in importance or is made illegal, local governance institutions and knowledge that ensure that fire use is controlled can also be lost, increasing the likelihood of anthropogenic wildfires. For example, anti-fire legislation in Ghana is leading to the loss of traditional village institutions that organised collective early-dry season burning to protect trees of spiritual and economic importance[38]. In Belize, Maya farmers with less time for swidden agriculture due to engagement in wage labour, cash cropping and pasture development are more likely to practice agricultural burns alone than in shared labour groups, and less likely to construct firebreaks before burning or remain onsite until a fire is extinguished[27].

Market-oriented fire practices are increasing globally.

Economic pressures can also drive increases in fire use: while subsistence-oriented fire use is declining, market-oriented fire use practices are increasing. New markets for certain products are driving increases in fire use associated with their production. For example, in Indonesia, a high value market for turtle meat emerged in the 1990s, driving increases in fire use to hunt turtles[39]. New technologies or infrastructural development may also drive increasing fire use. On the Indo-Gangetic

Plains, ‘green revolution’ technologies have enabled smallholders to adopt double cropping of rice-wheat, with the use of combine harvesters[40]. Under this cropping system there is limited time between harvest of rice and planting of wheat, and a greater biomass of crop residue left in-field. This means that farmers are now more likely to burn crop residues than collect them for other uses.

Among specific fire use purposes, only fire use to clear land for permanent agriculture, and protest fires (arson) show increasing trends in all three variables (proportion of population involved, proportion of landscape affected, and frequency of fire use in affected landscape patches) (Table 2). The increasing trend in protest fires is often linked to disputes over land, especially where commercial enterprises or protected areas restrict subsistence or smallholder land use. Its anonymity makes fire a well-documented ‘weapon of the weak’[22,41]. Arson is commonly used by smallholder farmers in Indonesia, for example, to assert their rights to land where large landholders have obtained land concessions from government[42].

Transitions to cash cropping in permanent agricultural systems tend to be driven by economic pressures, as with adoption of cashew as a cash crop by farmers in Guinea-Bissau[25]. In many cases, government policies also support transitions to permanent agriculture, like in Mexico, where it is promoted through agricultural subsidies[34]. Where economic pressures and policies support market-oriented permanent agriculture this can also be an indirect driver of increasing fire use associated with crop residue burning. This has been the case with smallholder rice-wheat cropping on the Indo-Gangetic Plains[40]. Crop residue burning does not, however, show a significant increasing trend across all case studies. This may relate to recent Government regulations on crop residue burning in many countries. In China, for example, crop residue burning has been banned since 1997[43].

While burning to clear land for swidden agriculture is significantly more likely to be decreasing in terms of the proportion of population practising it, or the proportion of the landscape affected, it is more likely to be increasing in frequency in affected landscape patches. This accords with observed global trends of declining area and declining fallow periods in swidden agriculture[44]. Shorter rotations and corresponding increases in fire use frequency are often linked to declining land availability per household. This can be related to expansion of commercial land uses or protected areas, or to population growth. It may also be that Government policies or incentive programs supporting permanent agriculture drive shortening fallow periods. In Brazil, participants in the Bolsa Floresta Program receive payments for ‘zero deforestation’, where ‘deforestation’ refers to opening fields in mature forest areas[45]. Clearing plots in secondary forests under a certain age of regrowth is permitted, incentivising farmers to practice short fallow swidden.

Generally, where economic pressures are driving increasing fire use, this fire use is less likely to be sensitive to environmental cues, which may increase wildfire risk and lead to negative ecological impacts. For example, in Indonesia, repeated burning to open areas for market-oriented fishing is transforming peatland forests into open floodplains[39]. Positive feedbacks between fire, removal of tree cover and loss of peat are increasing the susceptibility of these areas to wildfires.

Our knowledge of livelihood fire practices remains limited.

In each source, we looked for information about 37 variables for each fire practice (see supplementary table 1). Most sources only provided information for some of the variables of interest, so the coverage of LIFE is incomplete (Fig. 5). In part because this kind of data may be sensitive and difficult to collect, most case studies do not provide quantitative data regarding the fire return intervals or burned area of anthropogenic fires. This presents particular limitations for use of the database to improve global fire models. There is also particularly little data available on the social or demographic factors, such as age or gender, that shape participation in fire practices. Geographically, there are also data gaps, such as in eastern Europe and northern, western, and central Asia (Fig. 1). There are also far more studies discussing fire use than fire control and mitigation practices. These are areas that future case study research might address.

Despite the data gaps, there is potential to combine other forms of fire data with the quantitative and qualitative data from LIFE and future case studies, to improve our understanding of the implications of changes to smallholder and subsistence livelihood-oriented fire practices. Local or regional studies provide a precedent here. For example, in Mexico, social research on contemporary fire use has been used to help interpret the human fire signal in a dendrochronological record[46], and in Indonesia, local case study data has been combined with fire remote sensing data to study how local fire use practices shape the regional fire regime[42]. So far, case study data on fire use has not been combined with these other types of data at the global scale, nor has it been used to inform global fire models[16]. Our work to collate case study data at the global scale opens future possibilities to analyse how fire regimes and ecologies are shaped by fire use directed towards different livelihood outcomes.

Since the 1990s, there have been some efforts to design fire management programs based on traditional fire knowledge, in recognition of the ways in which subsistence-oriented fire use has shaped ecosystems or contributed to wildfire risk reduction. Perhaps the most advanced example of this is in Australia, where Aboriginal fire practices have informed the management of protected areas[47], and Aboriginal rangers are now being funded to conduct fire management via government-accredited methods for counting carbon credits[48]. Importantly, such programs often assume that standardised fire management can substitute for the contingent, livelihood-oriented practices of fire users, but this does not necessarily have the same ecological outcomes, nor lead to meaningful recognition of local fire users[22,49,50]. Future policies must make space for controlled fire use as it is already practised within local livelihoods. This will only be possible if the drivers of changes to these livelihoods are explicitly considered. We must better understand the social and environmental conditions under which economic pressures or state governance drive loss of fire use or less controlled fire use. We must also consider the cultural and economic factors that can drive the persistence of fire use in some places. The case studies in LIFE will be an important resource for further systematic analyses of these drivers.

Methods

A systematic literature review was used to find sources for inclusion in the LIFE database. Below we outline our search methodology, database structure, and methods for the analysis of trends in fire practices presented in this article.

Data sources

Published articles and books and 'grey literature' in the form of dissertations and unpublished reports, including non-English language sources, were included in LIFE. We were unable to include sources where we could not access them either online, or in libraries at the time of the research. The following criteria were used for inclusion of a source in LIFE: a) is written or published during or after the year 1995, with relevant data collection carried out during or after the year 1990; b) has a sub-national scale of analysis; c) is based on original empirical research (sources based on secondary data, or review articles were not included); d) discusses fire use or mitigation practices by smallholders or households with non-agricultural subsistence-oriented livelihoods, as practiced at the time of the research or practised within the living memory of research participants. We defined 'smallholders' as households for which agriculture is the principal source of livelihood, and which rely predominantly on family labour[51]. Such households usually produce at least a proportion of their crops and/or livestock for subsistence but may also produce a substantial amount for the market. We did not consider farm size in our definition, given that the amount of land required to make agriculture a viable livelihood varies significantly between countries, and different governments vary significantly in their legal definitions of the farm area considered a 'smallholding'[52].

The systematic literature review was initially conducted using the Clarivate Analytics Web of Science Core Collection. We applied a search string to the titles, keywords, and abstracts of all sources in the collection (see supplementary methods 1). The search results were filtered to remove all sources published before 1995, and to only include sources classified into a limited number of the Web of Science Research Areas (see supplementary methods 1). Our search yielded 3718 sources, of which 226 sources met our criteria for inclusion in LIFE. Searches were then made of several databases of fire-specific literature. We considered for inclusion all sources listed in six existing databases and literature reviews focused on human fire use[5,11,12,13,14,53]. Finally, we applied another search string to the titles and abstracts of all material in the catalogue of the Fire Research Institute Library[54] (see supplementary methods 1). These additional searches resulted in a further 87 sources for inclusion in LIFE. 279 more sources were then included based on 'snowball sampling' of the bibliography of each of the sources.

Structure of the LIFE database

In a preliminary version of LIFE, we mostly used free text to record information against the variables of interest. Later, based on qualitative analysis of this text, we developed categories to code the data for some of the variables. Where this was the case, the free text is maintained alongside the categorical data in the published database.

LIFE was created as a Microsoft Excel spreadsheet with three tabs, which respectively record information about individual sources, individual case study locations, and individual fire practices in those locations (see supplementary methods 1, supplementary table 1 and supplementary data 1). We grouped sources where they relate to research by the same author(s) in the same case study location(s) over a continuous period. Where a source or group of sources provided data separately for case studies in multiple locations, these were recorded as separate cases. Case studies in LIFE vary greatly in study area, from studies focused on single settlements to regional studies. For all cases, a single latitude and longitude point is provided to indicate the approximate centre of the study area, and each is coded into one of four categories to indicate the broad scale of the study area. When determining what constituted separate fire practices for inclusion in LIFE, we used the criteria by which the author(s) of the source(s) distinguished between practices. In most cases, authors distinguished fire practices based on their purposes (for example, ‘burning to clear land for swidden agriculture’ or ‘burning to drive game for hunting’). Sometimes authors made it clear that multiple fire use purposes related to the same ignitions on the landscape, in which case these were listed together as a single practice. In some cases, authors distinguished practices based on the seasons or locations in which they take place (for example, ‘fires set in the early dry season’).

Analysis of trends in fire practices

For each fire practice, we recorded whether a practice was increasing or decreasing in each of three variables: 1) the proportion of the population in the study area practising the practice; 2) the overall proportion of the study area affected by the practice annually; 3) the frequency with which the practice takes place in each patch of the landscape. Few sources reported on trends in practices in these terms, so we made judgements based on the information available. For example, if a source noted that expansion of intensive cropland in the study area had taken place at the expense of savanna areas in which subsistence hunting took place, we would record fire use for hunting as taking place over a decreasing proportion of the study area. Or, for example, if a source reported that younger generations were no longer learning to use fire for hunting, we would report fire use for hunting as taking place among a decreasing proportion of the population. For over 50 percent of practices, it was not possible to record the trend in any of these three variables (Fig. 3). We also noted where practices had been lost, but were remembered by research participants, or where practices were being (re)introduced based on traditional knowledge.

We then ran a two-tailed exact binomial test for each of the three variables for all subsistence-oriented practices, all market-oriented practices, and all fire use practices categorised under each of our 29 lower-tier fire use purpose types (Table 1). Here we tested whether the proportion of practices in each of these categories with a decreasing trend, or that had been lost, differed from what we would expect by chance alone (0.5). We treated results as significantly different from the null hypothesis with a P-value of less than 0.05. In running this test, we assumed that the case studies in LIFE were an unbiased sample of all smallholder and subsistence-oriented fire practices, i.e., that the authors of the studies in LIFE were not more likely to focus on practices that were increasing rather than decreasing, or *vice versa*. We believe that this assumption holds, given that LIFE draws on studies from a wide range of academic disciplines, and with a diversity of primary research topics (many studies discussed fire practices tangentially to other phenomena).

Data availability statement

The full LIFE database is included as supplementary data 1.

Code availability statement

The R computer code supporting the analysis presented in this study is included as supplementary methods 2.

Fig. 1. Map showing case study locations in the LIFE database, including those with fire practices that were actively practiced at the time of the case study research and those where practices had been lost but were practiced within the living memory of research participants.

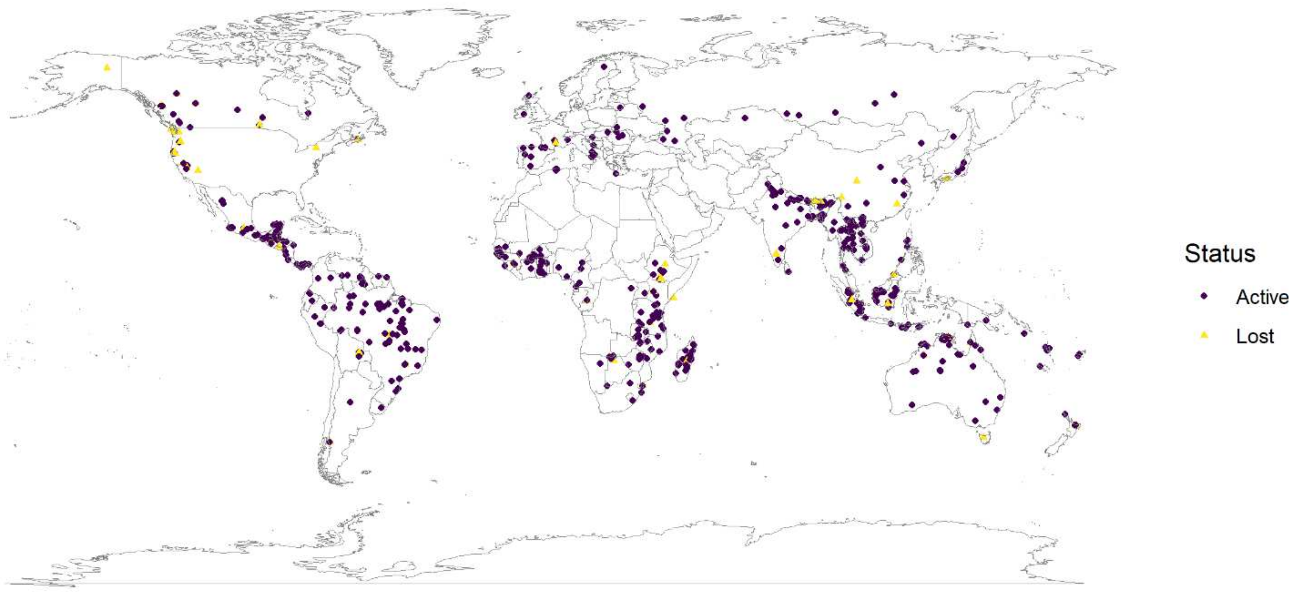


Table 1. Fire use purpose categories, and the number of examples of each in the LIFE database (*n*).

Fire use purpose		**Example**	***n***
Higher tier category	**Lower tier category**		
Agriculture	A1. Clear vegetation for swidden or semi-permanent agriculture	Lacandon Maya *milpa* swidden agriculture of corn, beans, and maize in Mexico[55].	325
	A2. Clear vegetation for permanent agriculture	Establishment of cashew plantations in Guinea-Bissau[25].	46
	A3. Clear weeds and/or crop residues during the growing season	Kayapó people in Brazil burning weeds in cassava swidden plots[56].	21
	A4. Clear weeds and/or crop residues after harvest to enable planting	Rice crop residue burning on the Trans-Gangetic Plains of India[40].	133
	A5. Reduce crop pests	Kanak people in New Caledonia burning to remove cover for wild pigs to protect tuber crops[57].	34
Pastoralism	P1. Clear vegetation to establish new pasture areas	Establishment of pasture by smallholder farmers in Pará, Brazil[58].	18
	P2. Enhance forage for grazing livestock	Pastoral burning in the Basque region of France[59].	216

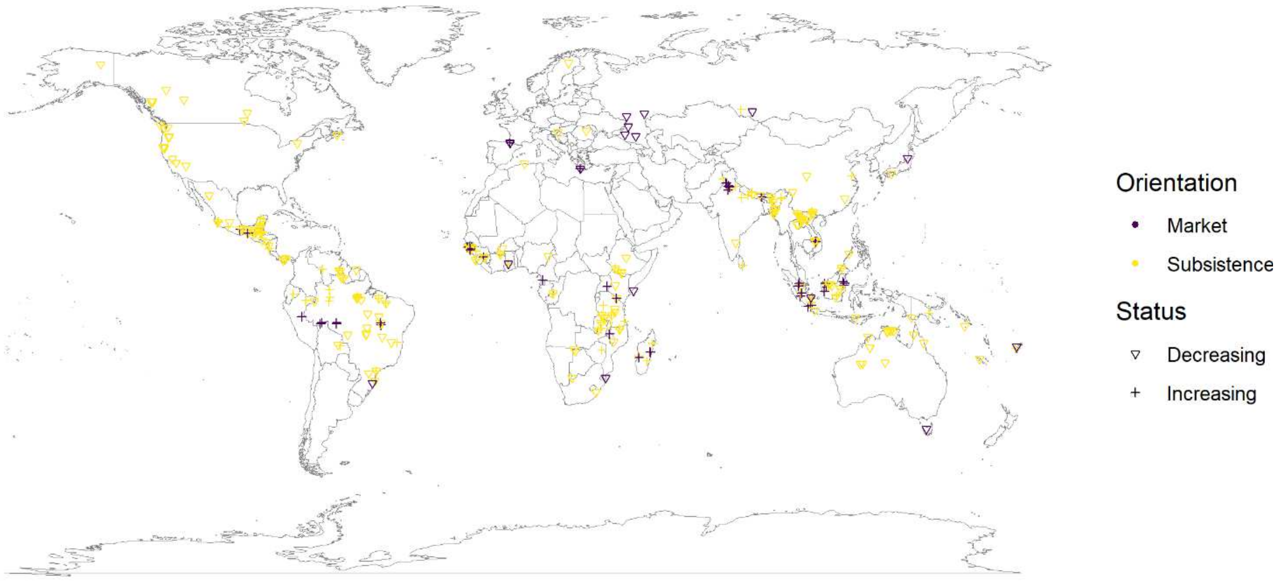
	P3. Herd livestock	Use of smoke by Evenk people in Siberia to draw reindeer close to camp, because of relief from biting insects.[60]	17
	P4. Reduce livestock pests and predators	Rangeland burning by Oromo people in the Bale Mountains, Ethiopia[61].	50
Hunting and fishing	HF1. Create or improve habitat for hunted or fished species	Burning to create pools for fishing in Indonesian peatlands[39].	24
	HF2. Renew forage to draw hunted or fished species into a particular area	Warlpiri people in Australia burning for fresh growth to attract kangaroos for hunting[62].	65
	HF3. Improve visibility or access specifically for hunting or fishing	Pemón people in Venezuela burning to remove tall and cutting grasses from river edges for fishing[63].	67
	HF4. Drive animals when hunting	Xavante ritual hunting drives in Brazil[64].	65
	HF5. Kill, injure, or tire animals when hunting	Teke-Alima people in Gabon burning to kill grasshoppers for gathering[65].	12
Gathering	G1. Enhance productivity of foraged resources	Western Mono tribes in California burning to promote black oak acorns and reduce oak pests[66].	134
	G2. Ease the collection of a foraged resource by improving visibility or access	Burning to clear the ground of leaf litter to facilitate collection of mahua flowers in Orissa, India[67].	41
	G3. Drive wild bees away from hives for honey collection	Dayak and Malay people smoking wild bees away from from bee trees in Indonesia[68].	48
Charcoal and firewood production	C1. Produce charcoal	Production of charcoal by Maasai women in Tanzania[69].	16
	C2. Produce fuelwood for gathering, or enable gathering of fuelwood	Khanyayo people in South Africa burning woodlands to speed up the drying process in wood that can be collected for fuel[70].	20
Movement	M1. Maintain and open trails and waterways for general access	Bayei people burning to clear vegetation blocking river channels in the Okavango delta[71].	50
Human health and wellbeing	HW1. Reduce animals that are dangerous to or unwanted by humans	Chiquitano people in Bolivia burning *pampas* to reduce hiding places for snakes[72].	62
	HW2. Reduce fuel loads to reduce risk of wildfires at a landscape scale	Fires set by Bambara and Malinke people in Mali fragment the fuel landscape to prevent large fires later in the dry season[19].	87
	HW3. Create firebreak using fire to protect e.g., resources, farms, sacred sites	Krahô people in Brazil burning to create firebreaks to protect fruiting trees[73].	44
	HW4. Suppress a wildfire (using backing fire to fight fire with fire)	Wapichan people in Guyana using backing fire to suppress wildfires[74].	6
	HW5. Produce a more aesthetically pleasing landscape, or for enjoyment	Métis people in Canada burning off dead grass in fields and around houses so new grass grows back thicker and greener, for aesthetic reasons[75].	23
Social signals	S1. Communicate about current activity	Khwe people in Namibia burning to signal to distant family members to notify them of location and success of a hunt[76].	17
	S2. Show disapproval or protest (arson)	Burning by Galician peasants in resistance to state forestry[77].	51
	S3. For ritual or ceremonies	Burning in Spanish chestnut forests in the cultural feast of the *Calbote*, marking summer's end and the start or end of the chestnut harvest[78].	16
	S4. Assert or maintain cultural identity	Banbai people in Australia burning to reinstate cultural practices and care for country[79].	112

Table 2. Trends in fire practices (codes for fire use purposes are given in table 1). '+' and blue colouration indicates a significant increasing trend (P<.05 in two-tailed binomial test). '-' and red colouration indicates a significant decreasing trend (P<.05 in two-tailed binomial test). 'NA' and white colouration indicates an insignificant trend (P>.05 in two-tailed binomial test).

Fire practice type	Proportion of population practicing	Proportion of landscape burned per year	Frequency of fire in each patch of landscape
All market oriented	+ (*n*=120, *P*<.001)	+ (*n*=145, *P*<.001)	+ (*n*=17, *P*=.01)
All subsistence oriented	- (*n*=328, *P*<.001)	- (*n*=378, *P*<.001)	- (*n*=219, *P*<.001)
A1	- (*n*=95, *P*<.001)	- (*n*=137, *P*<.001)	+ (*n*=95, *P*<.001)
A2	+ (*n*=33, *P*<.001)	+ (*n*=38, *P*<.001)	NA (*n*=2, *P*=.50)
A3	NA (*n*=11, *P*=1.00)	NA (*n*=12, *P*=1.00)	NA (*n*=0)
A4	NA (*n*=62, *P*=.25)	NA (*n*=62, *P*=.10)	NA (*n*=9, *P*=1.00)
A5	NA (*n*=10, *P*=.75)	NA (n=9, *P*=1.00)	NA (*n*=3, *P*=1.00)
P1	NA (*n*=7, *P*=.45)	NA (*n*=10, *P*=.11)	NA (*n*=1, *P*=1.00)
P2	- (*n*=83, *P*<.001)	- (*n*=96, *P*<.001)	- (*n*=39. *P*<.001)
P3	NA (*n*=8, *P*=.29)	NA (*n*=7, *P*=.45)	NA (*n*=5, *P*=1.00)
P4	- (*n*=15, *P*<.001)	- (*n*=16, *P*<.001)	NA (*n*=8, *P*=.07)
HF1	- (*n*=17, *P*=.01)	- (*n*=17, *P*=.01)	- (*n*=11, *P*<.001)
HF2	- (*n*=31, *P*<.001)	- (*n*=31, *P*<.001)	NA (*n*=14, *P*=.06)
HF3	- (*n*=37, *P*<.001)	- (*n*=34, *P*<.001)	- (*n*=16), *P*<.001
HF4	- (*n*=37, *P*<.001)	- (*n*=39, *P*<.001)	- (*n*=19, *P*<.001
HF5	- (n=7, *P*=.02)	- (n=7, *P*=.02)	NA (*n*=3, *P*=.25)
G1	- (*n*=78, *P*<.001)	- (*n*=83, *P*<.001)	- (*n*=61, *P*<.001)
G2	- (*n*=22, *P*<.001)	- (*n*=25, *P*<.001)	- (*n*=17, *P*<.001)
G3	- (*n*=9, *P*=.04)	- (*n*=10, *P*=.02)	NA (*n*=4, *P*=.13)
C1	NA (*n*=2, *P*=1.00)	NA (*n*=2, *P*=1.00)	NA (*n*=0)
C2	- (*n*=7, *P*=.02)	NA (*n*=4, *P*=.13)	NA (*n*=3, *P*=1.00)
M1	- (*n*=19, *P*<.001)	- (*n*=21, *P*<.001)	- (*n*=12, *P*=.006)
HW1	- (*n*=25, *P*<.001)	- (*n*=27, *P*<.001)	- (*n*=11, *P*=.01)
HW2	- (*n*=37, *P*<.001)	- (*n*=42, *P*<.001)	- (*n*=15, *P*<.001)
HW3	- (*n*=18, *P*<.001)	- (*n*=15, *P*<0.001)	- (*n*=11, *P*<.001)
HW4	NA (*n*=1, *P*=1.00)	NA (*n*=1, *P*=1.00)	NA (*n*=0)
HW5	- (*n*=17, *P*<.001)	- (*n*=19, *P*<.001)	NA (*n*=4, *P*=1.00)
S1	- (*n*=11, *P*<.001)	- (*n*=11, *P*<.001)	NA (*n*=5, *P*=.38)
S2	+ (*n*=7, *P*=.02)	+ (*n*=9, *P*=.004)	NA (*n*=1, *P*=1.00)
S3	NA (*n*=5, *P*=.06)	- (*n*=6, *P*=.03)	NA (*n*=3, *P*=.25)
S4	- (*n*=45, *P*<.001)	- (*n*=36, *P*<.001)	NA (*n*=13, *P*=.09)

Fig. 2

a. Map showing status (increasing or decreasing) of market- and subsistence-oriented practices in the LIFE database.



b. Status (decreasing/increasing) of market- and subsistence-oriented practices in the LIFE database, by practice type.

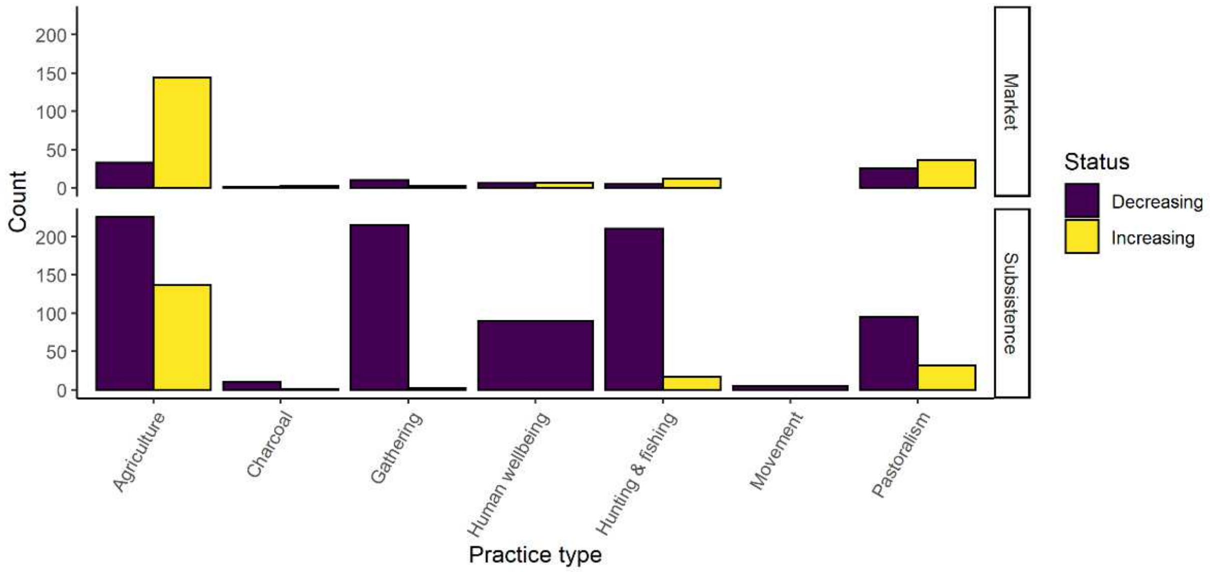
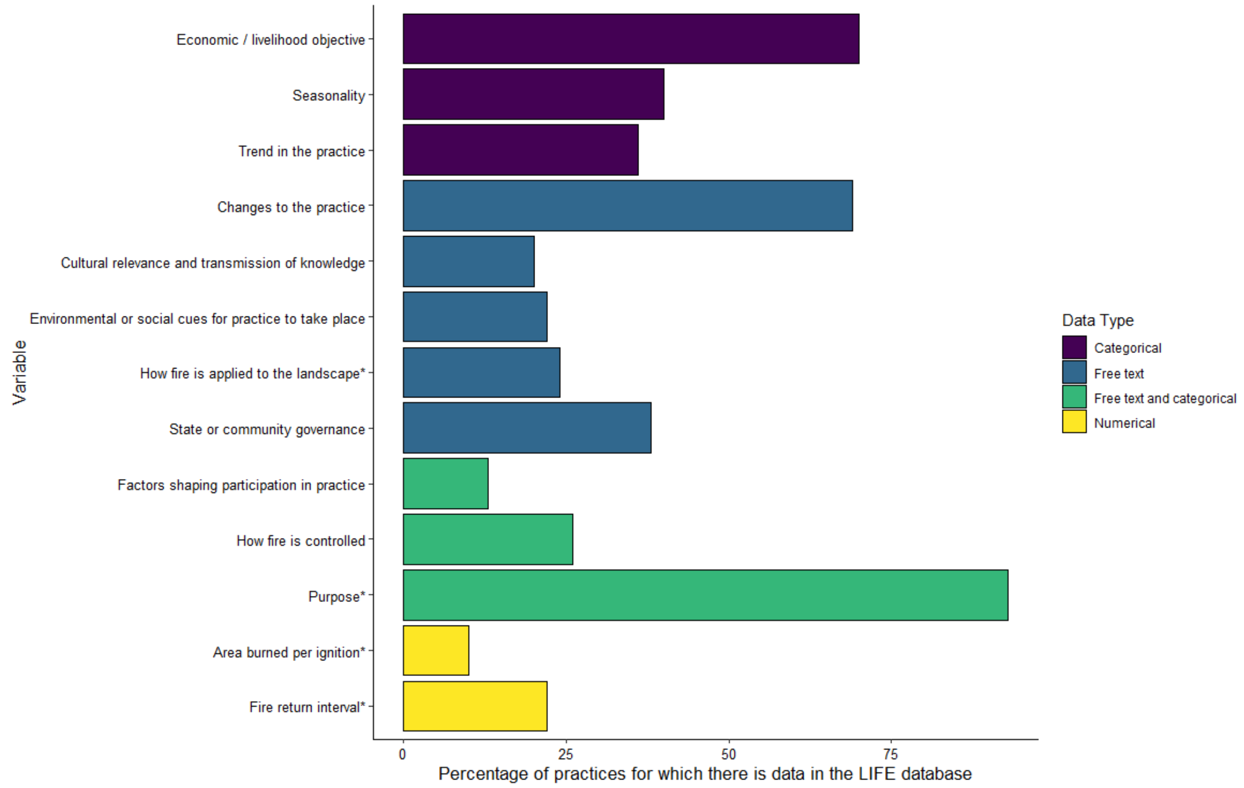


Fig. 3 Completeness of LIFE database for selected variables. *Variable applicable only to fire use practices.



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