# Conserving the Last Great Forests: A Meta-Analysis Review of the Drivers of Intact Forest Loss and the Strategies and Policies to Save Them

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The conservation of Earth's remaining intact forests (IFs) is a global priority, but improved understanding of the causes and solutions to IF loss is urgently needed to improve conservation efforts. This meta-analysis examines 207 case studies of IF loss occurring since 1970 to synthesize the drivers of IF loss and the proposed case-specific interventions. The goal of this study is to build a portfolio of conservation best practices for retaining IFs. The most frequently reported direct drivers of IF loss were logging, agriculture, ranching, and infrastructure expansion. Mining and fire were also prominent threats to IFs in selected areas. Indirect drivers of IF loss varied between continents, with high demographic pressures driving forest loss in Latin America, Asia, and Africa, contrasting with North America and Europe-Russia. Indirect economic and socio-political drivers were most frequently reported at the national scale for all continents studied, indicating a central role for national institutions in IF loss and conservation. Decisive socio-political factors underlying IF loss worldwide include political failures, institutional failures, and pro-development policies. A wide range of interventions were recommended in the case studies to conserve IFs. The proposed actions were most frequently within the forest, finance, and education and science sectors, and also emphasized inter-sectoral activities. Based on the results of this study, three core approaches to IF conservation that can be combined at the landscape scale are identified: protected areas, payments for ecosystem services, and agricultural reforms. Related enabling conditions include cooperative landscape management, effective enforcement, and political advocacy. The success of IF conservation efforts ultimately depends on sustained political support and the prioritization of high-value forest landscapes. Such efforts should mitigate socio-economic pressures through policy mixes that are cross-sectoral and place-based. Key policy priorities for IF conservation include addressing the systemic failures of public institutions, increasing political support for IF conservation, and countering harmful development activities.

Keywords: intact forest, forest conservation, deforestation, drivers, policy, strategy, meta-analysis

# INTRODUCTION

Intact forests (IFs) are a global conservation priority because they provide ecosystem services and vital resources and cultural benefits to local and global societies, especially forest-dependent indigenous people (Finer et al., 2008; Olivero et al., 2016). The loss of these relatively undisturbed native forests has both local and global consequences because human and natural ecosystems are dependent upon stable global carbon and hydrologic cycles and the ability of IFs to mitigate climate change impacts (Seymour and Busch, 2016; Watson et al., 2018). Documenting the loss of IFs has been a long-term priority in biodiversity conservation because the core habitats for many threatened forest-dependent species worldwide are found in IFs (Gibson et al., 2011; Betts et al., 2017; Donald et al., 2019). The threats to and losses of relatively undisturbed native forest ecosystems continue to be reported and recent estimates suggest that only ~25% of global forests are classified as intact (11 million km$^2$) (Heino et al., 2015). Between 2000 and 2012, ~324,000 km$^2$ of IF was lost, which is equal to a land area 1.3 times the size of the United Kingdom (Heino et al., 2015). Scientists and policy-makers have worked for decades to understand the causes of forest loss and to develop effective interventions (e.g., World Resources Institute, 1997; Lambin et al., 2003; Nepstad, 2005; Kissinger et al., 2012). While past efforts have helped to reduce deforestation in some areas (Nepstad et al., 2014; Thaler et al., 2019) and have improved the science of forest conservation (Puri et al., 2016; Min-Venditti et al., 2017), more effective approaches are needed to address the continued and widespread loss of IFs. Current research priorities include improved understanding of the causes of IF loss (Heino et al., 2015) and the development of more evidence to inform the design of place-based forest conservation efforts (Puri et al., 2016; Min-Venditti et al., 2017).

Underlying our need to better understand the drivers of IF loss is the reality that conservation interventions must be matched to the multi-scale drivers threatening IFs. Developing this knowledge can be difficult because the drivers of forest loss vary regionally and temporally due to variations in socio-economic conditions, land-use dynamics, population density, forest condition, and local biophysical conditions, among other factors (Lambin et al., 2003; Geist et al., 2006). This variation implies that efforts to conserve IFs must be place-based and informed by direct deforestation drivers, which operate locally (e.g., logging and mining), and indirect drivers, which are often external to the local area and outside the control of local land-users (e.g., market prices and technology; Geist et al., 2006). A diversity of scholars with different academic backgrounds have studied the direct and indirect drivers of forest change at several scales—global, regional, and local (e.g., Geist et al., 2006; Soares-Filho et al., 2006; Kissinger et al., 2012; DeFries et al., 2013). The existence of various disciplinary frameworks to understand the drivers of forest change suggests that IF conservation efforts be based on an interdisciplinary, and therefore holistic, approach to forming knowledge of the drivers of IF loss.

Designing effective IF conservation interventions must account not only for the location-specific drivers of forest change, but also overcome a lack of evidence regarding the efficacy of conservation policies and programs. In general, the field of evidence-based policy and program design for biodiversity conservation remains immature (Miteva et al., 2012; Baylis et al., 2016). Various forest conservation policies have been rigorously evaluated in recent decades, but even the most well-studied interventions suffer from a limited study of intervention outcomes and are not geographically representative (Puri et al., 2016). Limited evaluation data for past conservation efforts is problematic because the impacts of interventions, including unintended tradeoffs (Ferraro and Pattanayak, 2006; Puri et al., 2016) such as increased inequality or leakage (Hirsch et al., 2011), cannot be predicted accurately. Insufficient evaluation data may also hinder projections of conservation interventions because policy impacts can vary by efficacy, efficiency, equity, legitimacy, and partisan appeal (Salamon and Lund, 1989). Given the paucity of rigorous evaluations of forest conservation interventions and the multitude of potential outcomes, expanding the evidence used to inform IF conservation efforts and developing best practices for IF conservation efforts is an urgent scientific challenge.

In addition to insufficient knowledge about the impacts and trade-offs of IF conservation efforts, another key challenge is implementation. Even if a set of well-informed policies is designed to counter the drivers of forest loss, weak governance, institutional failure, and corruption may inhibit implementation and negate desired effects (Geist and Lambin, 2002; Laurance, 2004; Kissinger et al., 2012). The importance of institutional and political failure in policy implementation is rooted in the tradition of command-and-control governance widely used to regulate land-use (Lambin et al., 2014). Implementing conservation policies and enforcing compliance often requires adequate governance capacity and monitoring capabilities, which is problematic in most tropical forest countries (Kissinger et al., 2012; DeFries et al., 2013). Likewise, political support is necessary to enforce IF conservation laws and to develop new legislation, but political will may be lacking due to corruption (Ascher, 1999; Laurance, 2004) and the primacy of economic development (Geist et al., 2006; Nepstad et al., 2014). Policies that conserve IF may also create economic trade-offs that can be difficult to overcome in the face of powerful political actors and market forces (Wunder and Verbist, 2003). Thus, developing effective approaches to conserve IFs that identify and mitigate governance and institutional deficiencies and overcome existing economic and political trade-offs is a research priority.

To inform the aforementioned gaps in knowledge and the design of IF conservation efforts, this study examined the following questions: (1) what are the drivers of IF loss with respect to the case study literature?; (2) what IF conservation policies and activities are recommended in the case study literature?; and (3) can the synthesis of the case study's reported deforestation drivers and conservation recommendations inform the design of IF conservation policies and strategies?

# MATERIALS AND METHODS

Meta-analyses of case studies are widely used to provide systematic knowledge of scientific topics (Khan et al., 2001), including case-based analyses of the drivers of tropical

deforestation (e.g., Geist and Lambin, 2002; Rudel, 2007). Like all research methods, the case-oriented meta-analysis approach has strengths and limitations (Rudel, 2008). An important strength of the approach is the method's ability to identify broad patterns that explain the causes of land-cover change and inform policy development (Rudel, 2008; Magliocca et al., 2015). Drawing inferences from unique case studies can also present methodological challenges, including potential issues with inter-coder variability in the analysis of case studies (Rudel, 2005) and potential bias if cases are mostly focused on popular issues or regions of interest (Rudel, 2008). The following case-oriented meta-analysis sought to avoid potential biases by collecting a global sample of case studies of IF loss, extracting relevant data from each case study using two independent reviewers, and analyzing the case studies at continental and global levels. Continents studied were North America, Latin America, Europe-Russia, Asia, and Africa. Only two cases were identified related to IF loss in Australia-Pacific, so this area was excluded from the continental analyses. To reduce inter-coder variability and ensure that each reviewer utilized a similar approach to extracting information from a case, the reviewers were trained by the lead author using sample case studies. Reviewers then evaluated each assigned case independently before comparing and synthesizing their results with the reviewer who analyzed the same case. The data extracted from the cases was categorized and assessed using existing conceptual frameworks (**Table 1**).

The final dataset included 207 case studies from 193 publications documenting the drivers of IF loss at the local, regional, or national scale. Cases were identified and screened using the PRISMA-P meta-analysis protocol (Shamseer et al., 2015) (see **Appendix 1** for complete PRISMA search results). All cases included were peer-reviewed research articles, dissertations or master's theses, or related institutional publications. Cases were obtained using keyword searches in Google Scholar and the Web of Science database from the first 30 pages, showing 10 results per page. The following search terms were used: agricultural frontier, forest frontier, and deforestation frontier, as well as keyword searches constructed using the following methodology: "forest" + *climate* or *condition* keyword + *change* keyword. *Climate* keywords included dry, rainforest, tropical, subtropical, boreal, and temperate. *Condition* keywords included old-growth, intact, and primary. *Change* keywords included deforestation, conversion, and loss. For example, search strings included "dry forest deforestation" and "tropical forest loss." To be included, each case study had to describe IF loss at the local, regional, or national scale, occur partly or entirely after 1970, and contain information on the drivers of IF loss.

Based on the keyword searches and after screening the titles for relevance to the study, a total of 1,113 case studies were identified and a total of 483 duplicate studies were removed. The abstracts of the remaining 630 cases were then screened and 441 were excluded, leaving 189 cases (see **Appendix 1** for reasons for exclusion). An additional 41 records were obtained from reference lists and Google Scholar alerts, resulting in 230 records for full-text screening. After full-text screening 37 records were excluded, which resulted in a database of 193 records for study. Cases were organized and analyzed in Excel. The following data was extracted from each case study by each reviewer: direct and indirect drivers of change, institutional failures, political

**TABLE 1 |** The drivers of IF loss and the proposed conservation interventions extracted from the case studies.

| Variable extracted | Variable definition | Variable structure |
| --- | --- | --- |
| Direct drivers | Drivers locally responsible for forest conversion or degradation | (1) agricultural expansion; (2) infrastructure development; (3) wood extraction; (4) natural disturbances (e.g., fire, pests, drought); (5) mining and hydrocarbon extraction; and (6) ranching |
| Indirect drivers | Drivers that enable or encourage conditions that lead to forest conversion or degradation. | (1) demographic; (2) economic; (3) sociopolitical; (4) cultural and religious; and (5) scientific and technological. Drivers were recorded by spatial scale of local, national, and international |
| Institutional failures | Failures in public institutions that lead to forest loss or degradation | (1) weak or inadequate law enforcement; (2) poorly designed policies; (3) insufficient capacity; (4) failures in tenure regime; (5) poor planning; (6) poor coordination or collaboration; and (7) institutional corruption |
| Political failures | Failures by political actors that lead to forest conversion or degradation | (1) absent policies or insufficient political will; (2) political corruption; (3) failed policy effort; (4) unclear or ambiguous policies; (5) political instability or uncertainty; (6) insufficient or weak policies; and (7) insufficient funding |
| Pro-development policies | Forest development, natural resource extraction, or immigration policies implemented by political leaders or policy-makers | (1) encourage resource extraction; (2) encourage agriculture/pasture expansion; (3) encourage migration/colonization projects; (4) subsidies or tax incentives to deforest; (5) encourage/support infrastructure development; and (6) promotion of general economic growth. |
| Forest conservation interventions | Policy recommendations of case study authors to conserve forests | (1) sectoral policies; (2) inter-sectoral policies; and (3) unique policies and strategies |

*The direct drivers of IF loss were extracted using a modified version of the framework of Geist and Lambin (2002) and indirect drivers were identified using the framework developed by Nelson et al. (2006). The institutional and political failure typologies were produced based on results of the case studies and the political science concepts of policy failure, government failure, and institutional failure (Acheson, 2006; Howlett and Ramesh, 2014; Press, 2015).*

failures, pro-development policies, and proposed conservation policies or activities. The data extracted by each reviewer was then refined based on discussions between the paired case study reviewers. Bias was present in the form of the unequal global distribution of case studies. To control for this bias, extracted data was quantitatively analyzed and synthesized as a percent of the case studies at the global and continental scales. For a detailed description of each variable extracted see **Table 1**.

## RESULTS

### Case Studies of IF Loss Reviewed

The review of 193 publications produced 207 case studies of IF loss that formed the database used in this study. Data was collated across all major forest types, five continents, and 49 countries (**Appendices 2**, **3**). The most common reported forest type was tropical-subtropical wet forests (63% of cases), followed by tropical-subtropical dry forests (20%), temperate forests (8%), and boreal forests (8%). The case studies were mostly focused on Latin America (57%), followed by Asia (22%), Africa (10%), Europe-Russia (6%), and North America (5%). Eighty-nine percent of the cases were from developing countries and the remaining 11% were from developed countries.

### Global and Continental Direct Drivers

By order of frequency reported, the global direct drivers (i.e., proximate causes) of IF loss were agriculture, logging, and ranching (**Appendix 4**). However, logging was most frequently reported as the greatest contributor to IF loss in all continents studied with the exception of Latin America. In Asia, logging was followed by agriculture and infrastructure development, with ranching infrequently reported. In North America and Europe-Russia, logging was followed by natural factors (i.e., fire), with many of the fires reported caused directly or indirectly by humans. In Latin America, the most frequently reported direct driver of IF loss was agriculture followed by ranching and infrastructure development. Infrastructure development was reported to play a role in ≥50% of each of the continental analyses and mining and oil/gas drilling was reported in 19–31% of cases by continent. A continental analysis of the co-occurrence of agriculture and logging as driving IF loss found that 50% of the Europe-Russian cases and 40% of the North American cases reported logging as the primary reason for IF loss without identifying agriculture as a driver. In contrast, logging without agriculture was reported in only 13% of the cases from Africa and Asia and 4% of the cases from Latin America. Agricultural crops commonly reported to replace IFs at the continental level were soy in Latin America, palm oil and rubber in Asia, and corn in Africa.

### Global and Continental Indirect Drivers

The indirect drivers (i.e., underlying causes) of IF loss reported in the cases reviewed varied widely by continent and driver type (**Appendix 5**). Socio-political and economic indirect drivers were most commonly reported at the national scale for all continents at 55 and 63% of all cases, respectively. National and international economic drivers of IF loss were higher in Latin America, Asia, and North America compared to Europe-Russia and Africa. Notable economic factors identified across the cases included increasing commodity and land prices, poverty, and economic recession. National demographic factors were most commonly reported as IF loss factors in Africa (63% of cases), Latin America (48%), and Asia (36%). A continental analysis of the association between demographic factors and IF change identified four IF loss-demographic scenarios: high internal population growth, general internal migration, internal immigration caused by instability, and immigration from abroad. In Latin America, Asia, and Africa, the demographic factors of importance were internal population growth (34, 29, and 31% of cases, respectively), internal migration (39, 22, and 50% of cases, respectively), and migration due to internal instability (5, 2, and 19%, respectively). In Latin America and Asia, immigration was often associated with government-sponsored immigration projects and spontaneous colonist expansion due to poverty, whereas in Africa, immigration was associated with poverty and refugee movements caused by war and political unrest. With a few exceptions, cultural and religious drivers and scientific and technological drivers were reported in ≤10% of the continental case studies. Examples of cultural drivers reported included the transition from traditional hunting and gathering practices to subsistence agriculture and changes in traditional land-use practices. Examples of scientific and technological drivers reported included advances in seed varieties, improved irrigation technologies, and increased mechanization of logging operations and wood processing.

### Pro-development Policies and Political and Institutional Failures

A global and continental analysis of "pro-development" policies leading to IF loss found that 49% of all cases reported one or more pro-development policy, and the number of policies reported varied widely by continent. Pro-development policies were more commonly reported as driving IF loss in North America (50% of cases), Latin America (47%), and Asia (44%) compared to Europe-Russia (30%) and Africa (19%). In Latin America, the most frequent pro-development policies were associated with agriculture and pasture expansion, colonization schemes, and promotion of resource extraction (e.g., gold mining and logging). In Asia, the most common pro-development policies were agriculture expansion, promotion of resource extraction (i.e., logging), and infrastructure development. In North America, the pro-development policies most often reported were the promotion of resource extraction (i.e., logging) and agriculture expansion.

A common socio-political factor leading to IF loss is political failure (59% of all cases studied) due to the absence of political will or policies to conserve IFs (30% of all cases) (**Table 2**). Absence of political will or policies was most frequently reported on all continents except Asia, where political corruption and failed policy efforts were more frequently reported. In Africa, a multitude of factors drive political failure contributing to IF loss, including political corruption, lack of policies or political will, political instability, and insufficient or weak policies.

**TABLE 2 |** The table below shows the reported political failures at the global and regional scales leading to IF loss.

| Political failures | Global cases | Latin America | Asia | Africa | Europe—Russia | North America |
|---|---|---|---|---|---|---|
| % of cases with political failures | 59 | 55 | 67 | 69 | 40 | 70 |
| Absent policies or political will | 30 | 30 | 18 | 44 | 30 | 50 |
| Political corruption | 10 | 6 | 20 | 19 | 0 | 0 |
| Failed policy effort | 11 | 11 | 20 | 0 | 0 | 0 |
| Political instability or uncertainty | 10 | 9 | 4 | 38 | 10 | 0 |
| Insufficient or weak policies | 8 | 4 | 7 | 25 | 10 | 30 |
| Lack of funding | 5 | 5 | 0 | 13 | 10 | 0 |

*Results shown as a percentage of the total case studies reporting a political failure.*

**TABLE 3 |** The table below shows the reported institutional failures at the global and regional scales leading to IF loss.

| Institutional failures | Global cases | Latin America | Asia | Africa | Europe—Russia | North America |
|---|---|---|---|---|---|---|
| % of cases with institutional failures | 57 | 55 | 69 | 69 | 30 | 30 |
| Inadequate law enforcement | 26 | 25 | 36 | 31 | 10 | 0 |
| Poorly designed policies/planning | 5 | 4 | 9 | 13 | 10 | 10 |
| Insufficient institutional capacity | 12 | 13 | 11 | 6 | 10 | 0 |
| Issues with land tenure | 9 | 11 | 9 | 6 | 0 | 0 |
| Poor resource/development planning | 10 | 11 | 11 | 13 | 10 | 20 |
| Inadequate collaboration/coordination | 1 | 1 | 2 | 0 | 0 | 10 |
| Institutional corruption | 2 | 2 | 4 | 0 | 0 | 0 |

*Results shown as a percentage of the total case studies reporting an institutional failure.*

In North America, 80% of the cases reviewed reported the absence of political will or a lack of policies and insufficient or weak policies to conserve IFs. Another common indirect socio-political factor leading to IF loss is institutional failure, with 57% of all cases reporting a related institutional failure (**Table 3**). Globally, the most commonly reported institutional failure was inadequate law enforcement (26% of cases), followed by insufficient institutional capacity (12%), and poor resource/development planning (10%). Similarly, inadequate law enforcement was most frequently reported in Latin America, Asia, and Africa, followed by insufficient institutional capacity, and poor resource/development planning. Institutional failures were reported less frequently in Europe-Russia and North America.

## Recommended Policies and Strategies for IF Conservation

In the 207 case studies, a total of 456 interventions were recommended to address forest loss. Each intervention was classified and organized by its respective governance sector (**Appendix 6**). The most frequently recommended sectoral intervention was forest-conservation (53% of all recommendations), followed by inter-sectoral actions (13%), efforts within the finance sector (8%), and public education and science (8%). A sample of the policies and activities proposed within each sector is shown in **Appendix 6**. Interventions were assessed by how frequently they were recommended to address indirect or direct drivers of IF loss. The most frequently recommended interventions were forest governance (20% of cases), forest management activities (15%), protected areas (10%), collaboration and landscape governance (7%), and law enforcement and monitoring (7%). The least recommended interventions were sustainable land-use planning (2%), political advocacy and lobbying (<1%) and addressing corruption (<1%) (**Appendix 6**).

## DISCUSSION

The basic assumption of this research is that the long-term conservation of IFs depends on the integration of scientific knowledge and conservation efforts. Results from this meta-analysis show that the drivers of IF loss vary at the continental level, which adds further support to existing evidence that place-based conservation strategies are needed. As shown by this study, a wide variety of forest conservation policies are available. However, further research is needed to inform the design of IF conservation interventions for specific locations and to develop a portfolio of best practices. Improved understanding of the causes of IF loss and an overview of best practices for IF conservation is the focus of the following sections.

## Understanding and Linking the Drivers of IF Loss to Conservation Efforts

The meta-analysis results presented provide an overview of the case study literature describing the global and continental drivers of IF loss and their recommended conservation interventions. While the drivers of tropical forest loss are well understood (Geist and Lambin, 2002; Rudel, 2005; Kissinger et al., 2012), knowledge gaps remain with respect to the causes of IF loss (Heino et al., 2015). Echoing previous research on the causes of deforestation (Geist and Lambin, 2002; Kissinger et al., 2012), this study finds that IF loss is often directly due to a combination of factors, including agriculture, logging, infrastructure expansion, and ranching. Agriculture was the most frequently reported direct driver of IF loss at the global level, but logging was the most frequently reported continental direct driver, occurring in >85% of the case studies not in Latin America. This finding aligns with research conducted by Potapov et al. (2017), who used remote sensing to show that IF loss 2000–2013 was most frequently due to logging. Logging, agriculture, and ranching co-occurred with high frequency on most continents, but in North American and

European-Russian forests, logging was reported as a direct driver on its own at a higher frequency than Latin America, Asia, and Africa. This finding highlights how the boreal and temperate forests of North America and Europe-Russia are particularly threatened by the logging industry (Hansen et al., 2013; Potapov et al., 2017). Another key continental difference was the high frequency of ranching in Latin America but relatively low frequency in Asia. Also, while agriculture is a frequent driver on all five continents, the most commonly reported crops replacing IFs on three continents were distinct. The individual case studies also demonstrate that direct drivers often vary at regional and local levels. For example, at the local level, Scullion et al. (2014) found that the direct drivers of forest loss in Madre de Dios, Peru varied by land-use designations. At the regional level, Caldas et al. (2015) found that cattle ranching was the largest driver of change in the Paraguayan Chaco, which contrasts with other dry forest case studies in Latin America where conversion due to soya expansion was dominant (Pacheco, 2006; Volante et al., 2016). Common to all continents was the ubiquity of infrastructure development resulting in IF loss. A number of cases also reported mining and oil and gas extraction as drivers, but at lower frequencies. Overall, the direct drivers of IF loss vary widely at the continental level and often at regional and local levels as well. The broad geographic diversity of deforestation threats and the ubiquity of IF loss worldwide (**Appendices 2**, **3**) indicate that IF conservation efforts should focus on high-value regions. The strategy of regional prioritization of IF conservation efforts is reinforced by the finding that many "IF landscapes" (Potapov et al., 2008) lack the full complement of their native fauna (Plumptre et al., 2019). In other words, fully intact forests are increasingly rare and should be targeted for conservation efforts based on priority IF landscapes.

The indirect causes of IF loss also vary widely at the continental level. The three most frequently reported indirect drivers of IF loss were factors related to demographics, economics, and socio-politics. These factors can be summarized as increasing human demand for natural resources and the global trade in commodities, which drive local-to-global teleconnections (Carrasco et al., 2017) and endanger not only IFs but also wildlife (International Union for the Conservation of Nature, 2009; Estrada et al., 2019). In agreement with trends of global population growth and immigration (United Nations, 2019), clear differences were found between reported demographic pressures across continents, including higher frequencies of population growth and internal migration affecting IFs in developing countries. The causes of migration affecting IFs within developing countries were also variable, with colonization projects, poverty, and population growth being most reported in Latin America and Asia, and population growth, poverty, and refugee movements being most reported in Africa. These findings are insightful because they draw attention to the important and diverse role of human migration in IF change, which can include reductions or increases in forest cover depending on the circumstances (Radel et al., 2019). Economic factors were the most frequently reported indirect driver worldwide and most commonly reported on the same three continents with high levels of pro-development

policies: Latin America, Asia, and North America. The economic drivers reported were often linked to economic growth, but economic contraction and poverty also led to IF loss. These findings demonstrate that an important factor driving the continued loss of IFs, which are often geographically remote (Potapov et al., 2008), is their continued integration into global commodity supply chains. Since this integration threatens IFs, this study therefore suggests that conservation efforts should target the leading industries and pro-development policies on each continent. For example, in Latin America, the most frequently reported pro-development policies are the promotion of agriculture, pastures, and logging. Thus, primary targets in Latin America include the beef and soya industries and companies engaged in tropical forest logging. Similarly, priority conservation targets in Asia should include palm oil and logging companies, and in North America, logging companies. Interestingly, the least reported indirect drivers of IF loss, scientific and technological factors and cultural and religious practices, are likely relevant in far more cases than reported due to the central role of culture in influencing human behavior (Brislin, 1993; Schultz, 2011) and the importance of science and technology in driving economic expansion and environmental degradation (Millennium Ecosystem Assessment, 2005). Taken together, this study finds that meta-analysis studies of cases describing IF loss can inform the design and targeting of conservation interventions and confirms that the meta-analysis approach is limited by the biases and reporting of case study authors (Rudel, 2008).

The need to simultaneously target both market forces and national development policies and institutions to conserve IF is evident in this study by the high frequency of reported political and institutional failures driving IF loss. More than half of the case studies reviewed reported one or more political failure. Lack of political will or absent policies were especially problematic and pronounced in North America and Africa. Many studies have identified the role of political failures, including failed policy efforts, political corruption, political instability, and insufficient or weak policies as major threats to forests in the tropics (e.g., Ascher, 1999; Geist and Lambin, 2002; Kissinger et al., 2012). This study confirms these findings and shows that such drivers are worldwide threats to IFs. Similarly, echoing previous findings on the important role of institutional failure in forest loss (e.g., Dourojeanni, 1999; Kissinger et al., 2012; Rodrigues-Filho et al., 2015), this research found that institutional failures leading to IF loss occur worldwide and were reported in more than half of the cases studied. Overall, institutional failures were more frequently reported in developing countries than in developed countries. Across all continents, except for North America, inadequate law enforcement was the most frequently reported institutional failure, which aligns with other research showing that weak law enforcement is a persistent problem facing forests in developing countries (Kissinger et al., 2012). The relatively high frequency of failures related to law enforcement worldwide demonstrates that preventing IF loss is often not about writing new laws, but enforcing existing laws and regulations. Likewise, the frequency at which the lack of political will is cited indicates the importance of political advocacy to change the domestic politics that

surround IFs. However, increased political advocacy on behalf of IFs was rarely mentioned as a recommended conservation intervention. In many cases, the political reforms required to address issues of weak law enforcement and insufficient political will need to address the social inequities that often lead to IF loss (Dourojeanni, 1999) and the strengthening of political constituencies in favor of IF conservation and government accountability (Nepstad, 2005).

A key finding of this study is the relatively high frequency of indirect drivers of IF loss at the national level, including demographic, economic, and socio-political factors. The importance of these national-level factors in IF loss, particularly decisions made by national governments and corporations, is supported by others who have noted the key role of national-scale institutions in driving tropical deforestation (Wells et al., 2015; Nolte et al., 2017) and maintaining protected area effectiveness (Brandon, 1998; Bradshaw et al., 2015). Related evidence showing the importance of national-scale institutions in forest conservation outcomes includes the recent success of national initiatives to conserve large areas of forests in China, Vietnam, and Brazil (Liu et al., 2008; Meyfroidt and Lambin, 2009; Nepstad et al., 2014). Opportunities exist for international actors to catalyze domestic reforms through multilateral agreements that provide economic assistance or increased market access in return for reform. One example is the US-Peru trade agreement that required forest governance reforms in Peru for greater market access to the United States (Del Gatto et al., 2009). Similarly, international actors can incentivize nation-states to strengthen government institutions that manage IFs through international aid, such as the recent investments of Norway in Liberia, Indonesia, and Brazil (Rainforest Foundation Norway, 2018). While prioritizing conservation efforts at the national scale makes intuitive sense given the hierarchical structure of modern nation-states and the importance of national-level drivers of IF loss, this research also shows that important indirect drivers of IF loss are nested at local and international scales. In summary, future IF conservation efforts should design policies that target deforestation drivers at specific geographic scales and emphasize the targeting of national-level political systems, economic systems, and public institutions whose mission and activities influence IFs.

## Core IF Conservation Interventions

Individual conservation policies and activities can be understood as "tools in the toolbox" of potential forest conservation interventions because policy instruments are viewed as substitutable (Landry and Varone, 2005). That is, as shown in this study, a wide range of policies and strategies exist to conserve IFs and many of these approaches are useful under a range of circumstances. However, some policy instruments, such as payments for ecosystem services, are more specialized and only effective under certain conditions (Scullion et al., 2011; Wunder, 2013). Given the variation of policy impacts in different contexts and the lack of "policy panaceas" to resolve the overuse of natural resources (Ostrom, 2007), intelligent combinations of policy instruments, known as "policy mixes"

(Howlett, 2004), are needed to conserve IFs. The strength of policy mixes is that they are designed to create positive synergies between individual policies and contextual conditions (Howlett, 2004). The wide variety of policies identified in the case studies shows that numerous IF conservation policies are available. While there are many options available, we identified a set of conservation interventions that when implemented together at the landscape scale are likely to lead to long-term IF conservation: protected areas, payments for ecosystem services, and agricultural reforms. These policies were chosen because of their ability to target key drivers of IF loss identified in this study: land conversion for agriculture, logging, and ranching as well as market prices and politics favoring converted forests over IFs. The trade-offs of these core interventions and their related enabling conditions are discussed below.

### Protected Areas

Protected areas (PAs) form the foundation of global biodiversity and forest protection and are designed to prevent land-use change (United Nations Environmental Program, 2016). The effectiveness of PAs in conserving forests has been studied extensively with most studies finding that PAs slow or stop deforestation compared to unprotected lands (Joppa and Pfaff, 2011; Geldmann et al., 2013). The success of PAs depends on internal and external conditions, such as adjacency and intensity of nearby development and the density of park guards (Bruner et al., 2001; Joppa and Pfaff, 2011). Not all PAs are effective as many fail to maintain their biodiversity (Laurance et al., 2012) or are degazetted due to political pressure (Mascia and Pailler, 2011; Kroner et al., 2019). Establishing PAs on expanding forest frontiers may be helpful in the short-term, but without other supporting initiatives, such as regional land-use planning and law enforcement, their long-term maintenance may be too costly economically and politically. The main reasons for this being that PAs can result in the displacement of other land-uses (Dewi et al., 2013) and create political opposition (Mascia and Pailler, 2011). PA success is especially challenged in developing countries where institutions and political support for conservation are weaker (Ascher, 1999). Similar options but with fewer restrictions, such as indigenous reserves and multiple-use community forestry systems, have also been shown to be effective in maintaining forest cover (Nepstad et al., 2006; Blackman et al., 2017). Based on the aforementioned, we hypothesize that government-led PAs are more likely to effectively conserve IFs in North America and Europe-Russia and community-based systems more effective in Latin America, Asia, and Africa.

### Payments for Ecosystem Services (PES)

PES programs are an increasingly popular forest conservation strategy that can be used to conserve IFs in lieu of or in addition to PAs. PES programs come in a variety of forms, including carbon payments (e.g., REDD+) and payments for hydrological services (Porras et al., 2008; Angelsen and Rudel, 2013). The strength of the PES approach is that under the right conditions they create a market price for the services

of intact ecosystems that can compete with market prices for ecosystem conversion (Wunder, 2005). PES programs may also be advantageous because they can provide an equitable way to offset opportunity costs borne by land-users whose land-use is reduced by conservation efforts (Grieg-Gran et al., 2005). Major drawbacks to PES programs are that the payments are often marginal to the income of land-users and they may not compete with high returns from agriculture (Fisher et al., 2011; Scullion et al., 2014). PES interventions also require existing tenure regimes and effective law enforcement (Wunder, 2005), which are often lacking in remote or frontier regions. PES policies may also increase economic resources in poor regions and ultimately increase deforestation (Assunção et al., 2013). Nonetheless, as evidenced by the rush of national governments seeking to receive REDD+ funds, PES programs can provide a strong incentive to conserve forests (Kissinger et al., 2012). The REDD+ program and other multilateral funding programs that exchange cash for commitments to conserve forests offer promising ways to conserve IFs, but program criteria need to be adjusted to explicitly include IFs (Watson et al., 2018). In summary, given low payment prices, PES programs will work best to conserve IFs when land-use alternatives have low economic value. Also, effective law enforcement and stable public institutions are needed, which frequently excludes IF landscapes in developing countries.

## Agricultural Reforms
Because PAs are insufficient to conserve all species and landscapes (Soares-Filho et al., 2006) and because agricultural expansion is a leading cause of IF loss and forest loss worldwide (Kissinger et al., 2012), reforming the agricultural sector and including private lands in landscape-level conservation strategies is a key priority. Agricultural policies and programs designed to reduce deforestation include approaches known as "supply chain interventions" (Lambin et al., 2018), which aim to create market incentives to conserve forests and disincentives for deforestation. Transformation of the agricultural sector to conserve forests has increased rapidly in recent years due to consumer demand and the limited effect of public policies in slowing deforestation (Nepstad et al., 2013). Key efforts underway to transform agricultural supply chains include commodity roundtables, crop certification schemes, and corporate procurement policies, such as "no-deforestation" pledges (Nepstad et al., 2013; Rainforest Foundation Norway, 2018). A major downside to supply chain interventions is that they require other supporting policies because they are vulnerable to leakage and spillover effects (Schielein and Börner, 2018). Also, for local producers, crop certification schemes often have low returns because of high certification costs and low-price premiums (Nepstad et al., 2013). In areas of the landscape where PAs and PES payments are less effective due to weak governance or existing private land, agricultural reforms may be useful in all regions of the world studied. Also, while deforestation caused by smallholder shifting cultivation appears to be decreasing in relative terms compared to industrial agriculture (Austin et al., 2017), in Africa, Asia, and Latin America this form of farming remains a threat to IFs (Geist and Lambin, 2002; Potapov et al., 2017). Thus,

efforts to reduce the impacts of smallholder agriculture are also needed. Overall, the major related policy challenge is how to pair agricultural reforms with other multi-sectoral efforts that together ensure IF conservation, food security, and local income generation.

## Enabling Conditions for IF Conservation
Enabling conditions are necessary for the efficacy of the core IF conservation interventions described above and include cooperative landscape management, enforcement, and political advocacy. These three conditions were selected based on the high frequency of interventions recommended related to law enforcement and multi-sectoral actions, as well as their ability to increase political will for IF conservation.

## Cooperative Landscape Management
The diversity of cross-sectoral deforestation drivers and proposed inter-sectoral conservation interventions reported in this study highlight the necessity of cooperative landscape management. Cooperative landscape management involves collaborative management of mixed-use landscapes by land-users and institutions with management authority at the landscape-scale (Jacobson and Robertson, 2012), including combinations of PAs, working forests, and agricultural landscapes. The strength of this approach is that landscape-level collaborative efforts can break down sectoral silos, increase co-learning, and create shared responsibility to solve natural resource issues (Jacobson and Robertson, 2012; Kissinger et al., 2012). Various IF conservation interventions can be applied through cooperative landscape management, or "territorial approaches" (Nepstad et al., 2014), including strategic road planning (Laurance et al., 2014), deforestation bans and moratoriums (Fagan et al., 2013), forest zoning (Potapov et al., 2008), and land tenure reforms (Busch and Ferretti-Gallon, 2017).

## Enforcement
This study found that weak or absent law enforcement was the most frequently reported institutional failure in Latin America, Africa, and Asia. This situation is problematic because enforcement of the rules and laws underlying natural resource management is a prerequisite for conservation success (Ostrom, 1990). In general, effective law enforcement is associated with positive forest conservation outcomes (Agrawal et al., 2014). However, law enforcement can be economically costly and may present opportunity costs to land-users (Börner et al., 2014). Effective law enforcement also has the potential to exacerbate rural poverty and can raise questions about social justice and the legitimacy of force (Brechin et al., 2002). If used inhumanely or without policies to offset its opportunity costs to land-users, law enforcement will be politically unpopular and increasingly difficult to maintain (Brechin et al., 2002). These challenges may be overcome through community-based conservation efforts where local communities make and enforce their own rules (Ostrom, 1990; Cox et al., 2010). Relatedly, corruption threatens IFs worldwide and related law enforcement efforts are essential.

## Political Advocacy

Absent policies or political will was the most frequently documented political failure on all continents besides Asia. Political advocacy is necessary to conserve IFs in a democratic society to generate political will, challenge powerful actors, win political debates, and ensure government transparency. An engaged citizenry is also needed to conserve IFs because the ultimate cause of most conservation challenges is human behavior (Schultz, 2011), which manifests through politically negotiated outcomes and government institutions (Dietz et al., 2003; Fischer et al., 2012). Social movements and grassroots advocacy whose agendas are to influence environmental politics have long been instrumental in the legal protection of IFs, including wilderness protection in the United States (Turner, 2012) and the recent soy moratorium in the Brazilian Amazon (Rainforest Foundation Norway, 2018). Maintaining and expanding the protection of IFs will thus require increasingly effective political advocacy. Such advocacy should emphasize persuasive storytelling and building influential and diverse political constituencies, including corporations, politicians, young people, and forest-dependent communities.

## CONCLUSION

This study demonstrates that the synthesis of case studies of IF loss worldwide can be used to identify distinct continental patterns of indirect and direct drivers. This knowledge can be used to inform the design of place-based conservation interventions. A key finding from this study is the diversity of reported drivers of IF loss external to the forest-conservation sector. This reality implies that many of the most effective policy interventions will be extra-sectoral (Wunder, 2004). Critical non-forest sectors identified in this research include infrastructure, finance, and education and science. Ultimately, the inter-sectoral nature of IF loss implies the need to shift from a linear conservation dominated approach to a holistic multi-sectoral approach. Similarly, gaps in the recommended conservation interventions in the case studies include a lack of recommendations to address corruption, insufficient political will, and institutional weakness. Whether this issue is restricted to the case study literature or is a broader problem facing IF conservation efforts requires further analysis, but additional efforts are surely needed to increase political support, eliminate subsidies and tax incentives, and address corruption.

This meta-analysis shows that IFs face a variety of direct and indirect threats around the world. Successful IF conservation efforts require holistic, place-based, and multi-scale approaches focused on priority IF landscapes. Conservation efforts at the landscape-scale cross jurisdictional borders which creates challenges and opportunities for public-private partnerships (Scarlett and McKinney, 2016). Ultimately, the current paradigm of economic development must shift to make IF conservation the preferred policy option and not a trade-off that must be made. This approach requires the concerted efforts of scientists, policymakers, corporations, NGOs, and engaged citizens operating in governance regimes that link actors and institutions across global-to-local scales. To conserve IFs locally and globally thus requires many different actors to work together and for governance regimes to account for the telecoupled nature of resource flows and collective decision-making (Munroe et al., 2019). The structure for such collaborations is multi-scale governance whereby global and domestic institutions provide guidance, coordination, and monitoring and local and regional institutions ensure policies are fit to local conditions and include local stakeholders. Developing these polycentric governance systems (Nagendra and Ostrom, 2012) focused on landscape-level IF conservation will take generations, but the effort is surely worthwhile.

## AUTHOR CONTRIBUTIONS

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## SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/ffgc.2019.00062/full#supplementary-material

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