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Forest resources and land use change in Zambia: Examining the relationship between household-level attributes, contextual factors, deforestation and forest degradation, and their implications for livelihoods

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Abstract

Forest resources directly contribute to the livelihoods of about 90% of the 1.2 billion people living in extreme poverty. They indirectly support ecosystem services that sustain agriculture and food supplies of nearly half of the population in developing countries. In tropical and subtropical regions, forest resources are an important source of household income. Their contribution is almost as much as for crops and is greater than for non-farm and off-farm activities, livestock and wage labour. However, tropical and subtropical regions have exhibited high deforestation and forest degradation rates despite global declines in the last decades. This loss of forests has been primarily caused by expanding agricultural land and wood extraction, mainly for fuel. Thus, persistent loss of forests in tropical and subtropical areas impacts household resource dependence and the environment, which affects rural development and natural resource management. Despite previous interest in forests and livelihood research, no known studies have attempted to understand the relationships between household's socio-demographic and economic (household-level) attributes, contextual factors, deforestation and forest degradation, and their implications for livelihoods.

We conducted household surveys in 37 villages across the Miombo forest landscapes covering North-Western Province, Copperbelt and the Eastern Province in Zambia. Forest cover and deforestation data were derived from remotely sensed data. Furthermore, we used a sustainable livelihood framework to demonstrate the various relationships between household and contextual factors, forest livelihood strategies, deforestation, and forest degradation at the household level. In rural areas, households are the basic units in which decisions affecting people, forest resources, and the environment are taken. Thus, the sustainable livelihood approach recognises that within a specific context, households can use a combination of livelihood capitals including natural capital, human, social, economic and physical capital to arrive at different livelihood strategies, leading to (or not) the achievement of sustainable outcomes. These outcomes may include improved livelihoods and reduced deforestation.

The results of this research are presented in the form of three papers and a synthesis chapter: The first paper sought to understand the role of forest products in household forest use strategies and assess the impact of livelihood capitals on household forest use choices and related forest income in the Copperbelt Province's Miombo forest landscapes. We employed a cluster analysis technique to establish forest use strategies and a multinomial logistic regression model to determine factors associated with each forest use choice. As a result, we found that forest resources, both unprocessed and processed, accounted for more than half of total household income in the Copperbelt Province. The unprocessed forest products constituted most household subsistence activities, including forest foods, firewood, structures, and fibres. While processed products, primarily charcoal production, accounted for nearly 40% of household cash income. Households adopted three forest use strategies: pure subsistence-orientated forest users' strategy (49.5%), specialised charcoal sellers (32.3%) and forest food and charcoal sellers' strategy (18.2%). Households' forest use strategies were influenced by different combinations of livelihood capitals. Charcoal livelihood strategies were influenced mainly by natural and financial capital. In contrast, human capital and exogenous factors (infrastructure) influenced a pure subsistence-orientated forest livelihood strategy. Thus, while forest products are linked to improved livelihoods, they may have unintended adverse consequences for environmental sustainability.

In the second paper, we sought to understand the spatial patterns of deforestation and examine the effects of household-level attributes, including contextual factors and agricultural land use, on deforestation patterns along the Miombo forest transition gradient in Zambia. Deforestation values are computed for 36 spatial units (distance categories between households and land use patches) representing the areas of influence of households, such as agricultural land and forestlands. The North-Western Province, which represents early forest transition, has approximately 86% forest cover and a 0.48% annual deforestation rate. In contrast, the Copperbelt Province (mid forest transition) has the highest annual deforestation rate, at 1.15%, with 68% of forest cover. The Eastern Province, which represents advanced forest transition, has only 20% forest cover and the lowest annual deforestation rate of 0.29%.

Regarding deforestation across distance categories, we observed higher average deforestation rates at the close-distance category in the Copperbelt and North-Western Province and decreasing rates at medium-distance and remote-distance categories. While in the Eastern Province, we observed a reversed pattern across all distance categories. The spatial distributions of land use are linked to household-level attributes and contextual factors and differently influence deforestation and forest degradation along the Miombo forest transition gradient.

The significant factors, though different across provinces that are associated with household deforestation include socio-demographic attributes such as household size, ethnicity, education level and residence duration; land and non-land-based attributes such as large land size, large livestock units owned, higher incomes, mainly forest incomes, crop productivity, fish income, off-farm and non-farm incomes; and contextual factors (location attributes) such as access to permanent roads, distances to markets and agricultural land use. Regarding agricultural land use, we found that in the North-Western and the Copperbelt Province, higher deforestation patterns at close distances from households were associated with subsistence crop production. Simultaneously, commercial crop production was associated with reduced deforestation rates in areas further from settlements. In the Eastern Province, the high deforestation rates in remote areas are associated with subsistence crop production. These findings imply that the economic effects of distances between households and land use patches on deforestation vary depending on the stage of the forest transition but are unrelated to crop productivity.

The third paper examines the impact of socio-demographic attributes, economic factors and access to forest resources and markets on households' participation in forest support programmes in the Miombo forest landscapes. This paper tests multiple hypotheses regarding participation in forest support programmes. We found that household-level and contextual factors were significant and negatively associated with the likelihood of participation. These factors included household education level, landholding size, income shares, primarily forest income, crop and non-farm incomes, household location, and distances to markets and forestlands. In particular, we note that households with better education levels had lesser incentives to participate in forest support programmes.

Furthermore, improvements in household economic attributes, mainly non-farm activities, were more closely associated with decreased participation in forest support programmes. These findings imply that the economic costs of investing in education and non-farm income are likely to be higher in rural areas. As a result, affluent households are less likely to participate in interventions seeking to improve livelihoods while simultaneously improving the integrity of forests.

Overall, the findings of this research demonstrate the importance of a sustainable livelihood approach in understanding the various relationships between household attributes, contextual factors, livelihoods and land use change. This contributes to a better understanding of how diverse and complex interactions at the household level can affect livelihoods. Thus, we can deduce the following from the analysis of these interactions:

Forest products are essential components of rural livelihoods in the Miombo forest landscapes because they play a significant role in household forest use strategies. Thus, categorising households based on forest use can provide relevant information for targeted policy actions and programme designs to preserve the forests while simultaneously improving rural livelihoods. Furthermore, this research has shown that forest resources use contributes more than half of total household income, yet most households remain subsistence-orientated. Therefore, to enhance household income while preserving forest integrity, policies and interventions in the field must incorporate sustainable woodfuel production techniques, including reforestation and agroforestry methods.

This research also found that different types of livelihood capital have distinct effects on forest use strategies, suggesting the need to address underlying households' processes if sustainable rural development has to be achieved. For instance, access to forest resources was associated with higher extractive tendencies among households. This result partly indicates that assured ownership, such as customary/traditional forest management, is insufficient to address the challenges of sustainable forest management in Zambia. As such, we suggest that policies and interventions should promote sustainable production of forest resources by adopting improved techniques, including reforestation. This will ensure the integration of charcoal producers into the market system while at the same time encouraging subsistence forest users to engage in cash forest production.

This research further demonstrates that household-level causes of deforestation vary regionally across forest landscapes and along the forest transition. The results mean that integrating household surveys with remotely sensed data provides a better understanding of household-level attributes and agricultural land use on deforestation patterns in agrarian economies. This finding provides vital information for policymakers seeking to understand the underlying causes of deforestation to reconcile conservation policies with rural development agendas. It also provides relevant information for rural land use planning.

Additionally, the results suggest that agricultural land use can be associated with distances to settlements and deforestation along the forest transition gradient. However, the results do not support the views that suggest higher deforestation patterns closer to settlements (processing centres) can be associated with high return crops (commercial crops). This finding has several implications. First, the results imply that crop productivity does not consistently relate to distance categories and along the forest transition. Second, the results mean that deforestation patterns in the Miombo woodlands are mainly subsistence-driven and independent from return-related deforestation patterns. And lastly, this result implies that the von Thünen (1826) theory does not apply in agrarian economies with limited market depth.

For practice, this research has shown that the economic costs and benefits (business-as-usual scenarios) associated with different household processes such as investments in education, land and non-land-based income activities are important factors while considering forest intervention designs and implementation in the field. In terms of forest extraction, our results indicate that increased dependence on forest resources may jeopardise household participation in forest support programmes, as programmes may be perceived as restrictive. However, the results also demonstrate that non-forest-based livelihoods have higher opportunity costs than forest-related livelihoods. As such, households with higher non-forest-based incomes are unlikely to opt for forest extraction. Although there are significant differences in the impact of forest and non-forest-based livelihoods on participation, the findings suggest that improvements in household-level attributes can negatively affect household decisions to participate in forest support programmes in the Miombo areas of Zambia. Hence, we recommend that forest management interventions that aim to improve household well-being while preserving forests should target resource-poor households with limited incomes, lower education, and little access to markets.

Keywords: Smallholder households, livelihoods, forest resources, land use change, sustainable development.

Zusammenfassung

Waldressourcen tragen direkt zum Lebensunterhalt von etwa 90 % der 1,2 Milliarden Menschen bei, die global in extremer Armut leben. Indirekt unterstützen sie Ökosystemdienstleistungen, die die Landwirtschaft und die Nahrungsmittelversorgung von fast der Hälfte der Bevölkerung in Entwicklungsländern sichern. In tropischen und subtropischen Regionen sind Waldressourcen eine wichtige Quelle für das Haushaltseinkommen und ihr Beitrag ist fast so groß wie der von Feldfrüchten und größer als der von außerlandwirtschaftlichen Aktivitäten, Viehzucht und Lohnarbeit. In den letzten Jahrzehnten sind jedoch in den tropischen und subtropischen Gebieten trotz globaler Rückgänge hohe Entwaldungs- und Walddegradierungsraten zu verzeichnen. Dieser Waldverlust wurde in erster Linie durch die Ausweitung landwirtschaftlicher Flächen und die Holzgewinnung, welche hauptsächlich als Brennstoff genutzt wurde, verursacht. So wirkt sich der anhaltende Waldverlust in tropischen und subtropischen Gebieten auf die Abhängigkeit von Haushaltsressourcen und die Umwelt aus, was wiederum auf die ländliche Entwicklung und das Management natürlicher Ressourcen Auswirkungen hat. Trotz des bisherigen Interesses an Wäldern und der Forschung über Lebensunterhalte gibt es keine bekannten Studien, die versucht haben, die Beziehungen zwischen den soziodemografischen und wirtschaftlichen Eigenschaften von Haushalten, Kontextfaktoren, Entwaldung und Waldschädigung sowie deren Auswirkungen auf die Lebensgrundlagen zu verstehen.

Wir führten Haushaltsbefragungen in 37 Dörfern in den Miombo-Waldlandschaften der Nordwestprovinz, des Copperbelt und der Ostprovinz in Sambia durch. Die Daten zur Waldbedeckung und Entwaldung wurden aus Fernerkundungsdaten abgeleitet. Darüber hinaus wurde ein Rahmenwerk für nachhaltige Existenzsicherung verwendet, um die verschiedenen Beziehungen zwischen Haushalts- und Kontextfaktoren, Strategien für die Existenzsicherung im Wald, Entwaldung und Walddegradierung auf Haushaltsebene aufzuzeigen. In ländlichen Gebieten sind die Haushalte die grundlegenden Einheiten, in denen Entscheidungen getroffen werden, die Menschen, Waldressourcen und die Umwelt betreffen. Der Sustainable-Livelihood-Ansatz erkennt an, dass Haushalte innerhalb eines bestimmten Kontextes eine Kombination von Existenzgrundlagen, einschließlich Natur-, Human-, Sozial-, Wirtschafts- und Sachkapital, nutzen können, um verschiedene Existenzgrundlagenstrategien zu entwickeln, die letztendlich zu nachhaltigen Ergebnissen führen (oder auch nicht). Solche Ergebnisse können verbesserte Lebensgrundlagen und eine geringere Entwaldung sein.

Die Ergebnisse der zugrundliegenden Arbeit werden in Form von drei Veröffentlichungen und einem Synthesekapitel präsentiert:

In der ersten Veröffentlichung wurde die Rolle von Waldprodukten in den Waldnutzungsstrategien der Haushalte untersucht, um den Einfluss des Lebensunterhaltskapitals auf die Waldnutzungsentscheidungen der Haushalte und das damit verbundene Waldeinkommen in den Miombo-Waldlandschaften der Provinz Copperbelt zu bewerten. Wir setzten eine Clusteranalyse-Technik ein, um Waldnutzungsstrategien zu ermitteln, und ein multinomiales logistisches Regressionsmodell, um die Faktoren zu bestimmen, die mit jeder Waldnutzungswahl verbunden sind. Als Ergebnis stellten wir fest, dass Waldressourcen, sowohl unverarbeitete als auch verarbeitete, mehr als die Hälfte des gesamten Haushaltseinkommens in der Provinz Copperbelt ausmachten. Die unverarbeiteten Waldprodukte, einschließlich Waldnahrung, Brennholz, Strukturen und Fasern, machten die meisten Subsistenzaktivitäten der Haushalte aus, während verarbeitete Produkte, vor allem die Holzkohleproduktion, fast 40 % des Haushaltseinkommens ausmachten. Die Haushalte verfolgten drei Waldnutzungsstrategien: die Strategie der reinen subsistenzorientierten Waldnutzer (49,5 %), der spezialisierten Holzkohleverkäufer (32,3 %) und der Waldnahrungs- und Holzkohleverkäufer (18,2 %). Die Waldnutzungsstrategien der Haushalte wurden durch unterschiedliche Kombinationen von Lebensunterhaltsmitteln beeinflusst. Die Holzkohle-Strategien wurden hauptsächlich durch Natur- und Finanzkapital beeinflusst. Im Gegensatz dazu wurde die reine subsistenzorientierte Waldnutzungsstrategie von Humankapital und exogenen Faktoren (Infrastruktur) beeinflusst. Während Waldprodukte also mit einer verbesserten Lebensgrundlage verbunden sind, können sie unbeabsichtigte negative Folgen für die ökologische Nachhaltigkeit haben.

In der zweiten Veröffentlichung zielten wir darauf ab, ein besseres Verständnis der räumlichen Muster der Entwaldung zu erhalten und die Auswirkungen von Attributen auf Haushaltsebene einschließlich kontextueller Faktoren und landwirtschaftlicher Landnutzung auf Entwaldungsmuster entlang des Miombo-Waldübergangsgradienten in Sambia zu untersuchen. Die Entwaldungswerte wurden für 36 räumliche Einheiten (Distanzkategorien zwischen Haushalten und Landnutzungsflächen) berechnet, die die Einflussbereiche der Haushalte, wie z.B. landwirtschaftliche Flächen und Waldflächen, repräsentieren. Die Nordwestprovinz, die den frühen Waldübergang repräsentiert, hat eine Waldbedeckung von ca. 86 % und eine jährliche Entwaldungsrate von 0,48 %. Im Gegensatz dazu weist die Provinz Copperbelt (mittlerer Waldübergang) mit 68 % Waldbedeckung die höchste jährliche Entwaldungsrate von 1,15 % auf. Die Ostprovinz, die den fortgeschrittenen Waldübergang repräsentiert, hat nur 20 % Waldbedeckung und die niedrigste jährliche Entwaldungsrate von 0,29 %.

In Bezug auf die Entwaldung über Entfernungskategorien hinweg beobachteten wir höhere durchschnittliche Entwaldungsraten bei kleiner Entfernung im Copperbelt und in der Nordwestprovinz und sinkende Raten bei mittlerer und großer Entfernung . In der Ostprovinz beobachteten wir ein umgekehrtes Muster mit niedrigen Entwaldungsraten in allen Entfernungskategorien. Die räumlichen Verteilungen der Landnutzung sind mit Attributen auf Haushaltsebene und kontextuellen Faktoren verknüpft und beeinflussen Entwaldung und Walddegradation entlang des Miombo-Waldübergangsgradienten unterschiedlich.

Zu den bedeutenden Faktoren, die trotz Unterschiede zwischen den einzelnen Provinzen mit der Abholzung der Wälder in Verbindung gebracht werden, gehören soziodemografische Attribute wie Haushaltsgröße, ethnische Zugehörigkeit, Bildungsniveau und Wohndauer; land- und nicht-landbasierte Attribute wie große Landflächen, große Vieheinheiten im Besitz, höhere Einkommen, hauptsächlich Forsteinkommen, Ernteproduktivität, Fischeinkommen, außerlandwirtschaftliche und nichtlandwirtschaftliche Einkommen; und kontextuelle Faktoren (Standortattribute) wie Zugang zu festen Straßen, Entfernungen zu Märkten und landwirtschaftliche Landnutzung. In Bezug auf die landwirtschaftliche Landnutzung stellten wir fest, dass im Nordwesten und in der Copperbelt-Provinz höhere Entwaldungsmuster in geringer Entfernung zu den Haushalten mit Subsistenzpflanzenanbau in Verbindung gebracht wurden. Gleichzeitig war die kommerzielle Pflanzenproduktion mit geringeren Entwaldungsmustern in Gebieten verbunden, die weiter von Siedlungen entfernt waren.In der Ostprovinz sind die hohen Entwaldungsraten in abgelegenen Gebieten mit der Erzeugung von Pflanzen für den Eigenbedarf verbunden. Diese Ergebnisse deuten darauf hin, dass die wirtschaftlichen Auswirkungen von Entfernungen zwischen Haushalten und Landnutzungsflächen auf die Entwaldung je nach Stadium des Waldübergangs variieren, aber nicht von der Pflanzenproduktivität abhängig sind.

Die dritte Veröffentlichung untersucht den Einfluss von soziodemografischen Merkmalen, ökonomischen Faktoren und dem Zugang zu Waldressourcen und Märkten auf die Teilnahme der Haushalte an Waldförderprogrammen in den Miombo-Waldlandschaften. In dieser Arbeit testen wir mehrere Hypothesen zur Teilnahme an Waldförderprogrammen. Wir fanden heraus, dass Faktoren auf Haushaltsebene und kontextuelle Faktoren signifikant und negativ mit der Wahrscheinlichkeit der Teilnahme verbunden waren. Zu diesen Faktoren gehörten das Bildungsniveau des Haushalts, die Größe des Landbesitzes, der Anteil des Einkommens, das hauptsächlich aus dem Wald stammt, das Einkommen aus der Landwirtschaft und anderen Bereichen, der Standort des Haushalts und die Entfernung zu Märkten und Waldgebieten. Insbesondere stellen wir fest, dass Haushalte mit einem höheren Bildungsniveau einen geringeren Anreiz hatten, an forstlichen Förderprogrammen teilzunehmen.

Darüber hinaus waren Verbesserungen bei den wirtschaftlichen Merkmalen der Haushalte, hauptsächlich bei nichtlandwirtschaftlichen Tätigkeiten, stärker mit einer geringeren Beteiligung an Waldförderprogrammen verbunden. Diese Ergebnisse implizieren, dass die wirtschaftlichen Kosten für Investitionen in Bildung und außerlandwirtschaftliches Einkommen in ländlichen Gebieten wahrscheinlich höher sind. Infolgedessen ist es weniger wahrscheinlich, dass wohlhabende Haushalte an Maßnahmen teilnehmen, die darauf abzielen, den Lebensunterhalt zu verbessern und gleichzeitig die Integrität der Wälder zu verbessern.

Insgesamt zeigen die Ergebnisse dieser Forschung, wie wichtig ein nachhaltiger Lebensunterhaltsansatz ist, um die verschiedenen Beziehungen zwischen Haushaltsattributen, Kontextfaktoren, Lebensunterhalt und Landnutzungsänderungen zu verstehen. Dies trägt zu einem besseren Verständnis dafür bei, wie vielfältige und komplexe Interaktionen auf Haushaltsebene die Lebensgrundlagen beeinflussen können. Somit können wir aus der Analyse dieser Wechselwirkungen folgendes ableiten:

Waldprodukte sind wesentliche Bestandteile des ländlichen Lebensunterhalts in den Miombo-Waldlandschaften, da sie eine bedeutende Rolle in den Waldnutzungsstrategien der Haushalte spielen. Daher kann eine Kategorisierung der Haushalte auf Basis der Waldnutzung relevante Informationen für gezielte politische Maßnahmen und Programmdesigns liefern, um die Wälder zu erhalten und gleichzeitig die ländlichen Lebensgrundlagen zu verbessern. Darüber hinaus hat diese Untersuchung gezeigt, dass die Nutzung der Waldressourcen mehr als die Hälfte des gesamten Haushaltseinkommens ausmacht, die meisten Haushalte jedoch weiterhin auf Subsistenz ausgerichtet sind. Um das Einkommen der Haushalte zu verbessern und gleichzeitig die Integrität der Wälder zu erhalten, müssen daher politische Maßnahmen und Interventionen vor Ort nachhaltige Techniken zur Holzbrennstoffproduktion einbeziehen; dies kann Wiederaufforstung und Agroforstmethoden beinhalten.

Diese Studie ergab auch, dass verschiedene Arten, den Lebensunterhalt zu verdienen, unterschiedliche Auswirkungen auf Waldnutzungsstrategien haben. Das deutet darauf hin, dass die zugrunde liegenden Prozesse der Haushalte angegangen werden müssen, wenn eine nachhaltige ländliche Entwicklung erreicht werden muss. Beispielsweise war der Zugang zu Waldressourcen mit einer höheren Extraktionstendenz bei den Haushalten verbunden. Dieses Ergebnis deutet zum Teil darauf hin, dass gesicherte Eigentumsverhältnisse, wie z.B. die gewohnheitsmäßige/traditionelle Waldbewirtschaftung, unzureichend sind, um die Herausforderungen einer nachhaltigen Waldbewirtschaftung in Sambia zu bewältigen. Daher schlagen wir vor, dass politische Maßnahmen und Interventionen die nachhaltige Produktion von Waldressourcen durch die Einführung verbesserter Techniken, einschließlich der Wiederaufforstung, fördern sollten. Dies wird die Integration von Holzkohleproduzenten in das Marktsystem sicherstellen und gleichzeitig Subsistenz-Waldnutzer dazu ermutigen, sich in der Cash-Waldproduktion zu engagieren.

Diese Forschung zeigt außerdem, dass die Ursachen für die Entwaldung auf Haushaltsebene regional über Waldlandschaften und entlang des Waldübergangs variieren. Die Ergebnisse bedeuten, dass die Integration von Haushaltsbefragungen mit Fernerkundungsdaten ein besseres Verständnis der Eigenschaften auf Haushaltsebene und der landwirtschaftlichen Landnutzung auf Entwaldungsmuster in Agrarwirtschaften ermöglicht. Dieses Ergebnis liefert wichtige Informationen für politische Entscheidungsträger, die versuchen, die zugrundeliegenden Ursachen der Entwaldung zu verstehen, um Naturschutzmaßnahmen mit Agenden der ländlichen Entwicklung in Einklang zu bringen. Diese Ergebnisse auch relevante Informationen für die ländliche Landnutzungsplanung.

Zusätzlich deuten die Ergebnisse darauf hin, dass die landwirtschaftliche Landnutzung mit der Entfernung zu Siedlungen und der Entwaldung entlang des Waldübergangsgradienten in Verbindung gebracht werden kann. Die Ergebnisse unterstützen jedoch nicht die Ansichten, die nahelegen, dass höhere Entwaldungsmuster in der Nähe von Siedlungen (Verarbeitungszentren) mit ertragreichen Kulturen (kommerziellen Kulturen) in Verbindung gebracht werden können. Dieses Ergebnis hat mehrere Implikationen. Erstens bedeuten die Ergebnisse, dass die Ernteproduktivität nicht konsistent mit den Entfernungskategorien und entlang des Waldübergangs zusammenhängt. Zweitens bedeuten die Ergebnisse, dass die Entwaldungsmuster in den Miombo-Wäldern hauptsächlich subsistenzgetrieben und unabhängig von ertragsbezogenen Entwaldungsmustern sind. Und schließlich impliziert dieses Ergebnis, dass die Theorie von Thünen (1826) in Agrarwirtschaften mit begrenzten Märkten nicht anwendbar ist.

Für die Praxis hat diese Untersuchung gezeigt, dass die ökonomischen Kosten und Nutzen (Business-as-usual-Szenarien), die mit verschiedenen Haushaltsprozessen wie Investitionen in Bildung, Land und nicht landbasierte Einkommensaktivitäten verbunden sind, wichtige Faktoren sind, wenn man die Gestaltung und Umsetzung von Waldinterventionen im Feld betrachtet. In Bezug auf die Waldentnahme deuten unsere Ergebnisse darauf hin, dass eine erhöhte Abhängigkeit von Waldressourcen die Teilnahme der Haushalte an Waldförderprogrammen gefährden kann, da die Programme als restriktiv wahrgenommen werden können. Die Ergebnisse zeigen jedoch auch, dass nicht waldbasierte

Lebensgrundlagen höhere Opportunitätskosten haben als waldbezogene Lebensgrundlagen. Daher ist es unwahrscheinlich, dass sich Haushalte mit höheren nicht-waldbezogenen Einkommen für die Waldentnahme entscheiden. Obwohl es signifikante Unterschiede in der Auswirkung von forstwirtschaftlichen und nicht forstwirtschaftlichen Lebensgrundlagen auf die Teilnahme gibt, deuten die Ergebnisse darauf hin, dass Verbesserungen auf Haushaltsebene die Entscheidung der Haushalte zur Teilnahme an Waldförderprogrammen in den Miombo-Gebieten Sambias negativ beeinflussen können. Daher empfehlen wir, dass Waldbewirtschaftungsmaßnahmen, die das Wohlergehen der Haushalte verbessern und gleichzeitig die Wälder erhalten wollen, auf ressourcenarme Haushalte mit geringem Einkommen, niedriger Bildung und wenig Zugang zu Märkten abzielen müssen.

Schlüsselwörter: Kleinbauernhaushalte, Lebensgrundlagen, Waldressourcen, Landnutzungsänderung, nachhaltige Entwicklung.

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1. Introduction

Global rates of deforestation and forest degradation have declined over the last three decades, but the rates in the tropical and subtropical regions have remained markedly high (FAO, 2020b). Tropical and subtropical forests are classified as dry tropical forests, wet and humid tropical forests (Murphy & Lugo, 1986) and occupy more than half of the world's forests (tropical forest, 45% and subtropical forests, 11%) (FAO, 2020a, 2020b). Dry tropical forests account for nearly half (about 42%) of the tropical and subtropical forests, supporting millions of households (Chao, 2012; Hasnat & Hossain, 2020), but are also subject to the most disturbances (Schröder, Rodríguez, & Günter, 2021). For example, in sub-Saharan Africa, Bodart et al. (2013) estimate annual deforestation and forest degradation at 0.37% and 0.34%, respectively, higher than the regional rate of 0.34% and 0.32%. This continued loss of forests affects households' resource dependence and environmental outcomes, which can have ramifications for rural development and natural resource management.

Forest resources directly contribute to the livelihoods of about 90% of the 1.2 billion people living in extreme poverty. They indirectly support ecosystem services that sustain agriculture and food supplies of nearly half of the population in developing countries (Chao, 2012; World Bank, 2004). In addition, forests account for about 22.2% of household incomes in developing countries, mainly in tropical and subtropical regions (Angelsen et al., 2014). This contribution is almost as much as for crops and is greater than for non-farm and off-farm activities, livestock and wage labour (Angelsen et al., 2014). Therefore, tropical and subtropical dry forests play a critical role in household livelihoods because they support as many poor households as wet tropical forests, boreal and temperate forest regions combined (Blackie et al., 2014; Chao, 2012; Djoudi, Vergles, Blackie, Koame, & Gautier, 2015; Hasnat & Hossain, 2020; Sachs, 2001).

In Africa, for example, the Miombo ecosystem is the most extensive dry forest woodlands and supports about 100 million people living in and around the forest areas (Byers, 2001; Dewees et al., 2010). The Miombo woodlands contribute to household subsistence, generate cash income, and support households' energy requirements for households living in rural and urban areas (Smith, Hudson, & Schreckenberg, 2017; Zulu & Richardson, 2013). The main forest products contributing to household’s income are wood extraction for firewood and charcoal production, poles for construction, forest food, and timber (Emmanuel N Chidumayo & Gumbo, 2010; Djoudi et al., 2015; Jones, Ryan, & Fisher, 2016; Njana, Kajembe, & Malimbwi, 2013; Zulu & Richardson, 2013). In Zambia, for example, the Miombo woodlands contribute approximately 35 to 50% of household subsistence and cash incomes (Kalaba, Quinn, &

Dougill, 2013a; Mulenga, Richardson, Tembo, & Mapemba, 2014) and support nearly half (44%) of urban energy needs through charcoal use (Tembo, Mulenga, & Sitko, 2015). Thus, the Miombo woodlands are a classic example of forest destruction in tropical dry forest areas caused by rational human actions (Njana et al., 2013; D. Phiri, Morgenroth, & Xu, 2019b; Schröder et al., 2021).

Furthermore, in the Miombo areas of Zambia, forest resources extraction is intertwined with household livelihood strategies (Dewees et al., 2010; Handavu, Chirwa, & Syampungani, 2019; C. B. Jumbe, Bwalya, & Husselman, 2008; Kalaba et al., 2013a). This suggests that rural households are the de facto forest managers who use forests for subsistence and cash income generation (Dewees et al., 2010; Dyer et al., 2014; Jones et al., 2016; Mulenga et al., 2014; Njana et al., 2013). In recent years, researchers in human and environmental studies have attempted to examine the relationships between household processes, livelihood strategies and natural resources, particularly in the tropical regions (Adhikari, Di Falco, & Lovett, 2004; A. Ali & Rahut, 2018; Angelsen et al., 2014; Babigumira et al., 2014; Babulo et al., 2008; De Sherbinin et al., 2008; Duguma et al., 2019; Kamanga, Vedeld, & Sjaastad, 2009; Kusters, Achdiawan, Belcher, & Pérez, 2006; Sunderlin et al., 2005; Vedeld, Angelsen, Bojö, Sjaastad, & Berg, 2007; Wunder, Angelsen, & Belcher, 2014). These studies have analysed the relationships between household socio-demographic attributes such as age, gender, household size, education, residence and ethnicity; and contextual factors such as institutions, markets and forest cover and landscapes variability; and natural resources such as firewood and forest foods. However, studies integrating household surveys and remotely sensed data at the household scale to investigate these dynamic household-level attributes and contextual factor relationships, including land use change, are limited.

Our research seeks to understand the relationships between households' socio-demographic and economic attributes, contextual factors, forest livelihood strategies, deforestation and forest degradation, and by extension, understanding their impacts on sustainable rural outcomes. We focus on rural households because they form more than half of the population in most countries in tropical and subtropical regions (World Bank, 2021). Furthermore, households are the major actors in agricultural land use and forest resources extraction in most areas with tropical and subtropical dry forests (Angelsen et al., 2014; Gibbs et al., 2010; Mamo, Sjaastad, & Vedeld, 2007; Vedeld et al., 2007). As such, smallholder households play an important role in landscapes and forest cover change (Babigumira et al., 2014; Etter, McAlpine, Wilson, Phinn, & Possingham, 2006; Rudel, 2013), and foodstuff and forest products supply to cities and urban areas (Djurfeldt, 2015; Vandercasteelen, Beyene, Minten, & Swinnen, 2018; Zulu & Richardson, 2013). Therefore, a better understanding of households processes provides insights into how socio-demographic and economic attributes, livelihood capitals (resources), can affect livelihood strategies (forest livelihoods) (Babulo et al., 2008; Nguyen, Do, Bühler, Hartje, & Grote, 2015; Soltani, Angelsen, Eid, Naieni, & Shamekhi, 2012), and deforestation and forest degradation (A. Ali & Rahut, 2018; Babigumira et al., 2014; De Sherbinin et al., 2008; Handavu et al., 2019; Hosonuma et al., 2012). Moreover, the connections between household socio-demographic attributes, livelihood strategies, and deforestation and forest degradation are mediated by contextual factors, specifically, access to forestlands, distances to markets, and landscape and forest cover variability (Babigumira et al., 2014; Call et al., 2017; Duguma et al., 2019). Thus, these multiple and diverse linkages can influence or not affect the achievement of sustainable rural outcomes and affect households' wellbeing (Angelsen et al., 2014; De Sherbinin et al., 2008; Sunderlin et al., 2005).

1.1. The conceptual framework

We apply a sustainable livelihood (SL) approach at the household level to understand the relationships between household-level attributes and contextual factors, forest livelihood strategies, deforestation and forest degradation, and their implications for livelihoods (Figure.1). In tropical and subtropical regions, particularly rural areas, households are the basic units in which decisions affecting people, forest resources and the environment are taken (De Sherbinin et al., 2008). The SL approach describes the various livelihood strategies and activities households pursue (Scoones, 1998; Serrat, 2017). This approach recognises that within a specific context, households can use a combination of livelihood capitals such as natural capital, human, social, economic and physical capital to arrive at different livelihood strategies (Scoones, 1998). These attributes can adversely affect deforestation and forest degradation, thus leading to (or not) the achievement of sustainable outcomes (Duguma et al., 2019). Therefore, the SL approach describes households as homogenous and, thus, a single unit for analysis (see also De Sherbinin et al., 2008).

Studies on forests and livelihoods suggest that differences in household-level attributes, specifically age, gender, household size, residence duration, education and ethnicity; contextual factors including access to forestlands, markets, and forest cover variability differently affect livelihood outcomes (Angelsen et al., 2014; Shackleton & Shackleton, 2006). For example, older household heads in Zambia were less likely to engage in charcoal production because charcoal activities were considered labour-intensive (Handavu et al., 2019; Mulenga et al., 2014). While in Malawi, gender differences determined participation in charcoal production (Smith et al., 2017). Previous research has not adequately explained the complex and dynamic linkages between household attributes, contextual factors, livelihoods, deforestation, and forest degradation in tropical forest areas despite this heterogeneity in household processes.

Rural households in tropical forest areas frequently pursue various livelihood strategies that may include multiple activities such as forest product harvesting, crop farming, fishing, and off-farm and non-farm activities (Djoudi et al., 2015; Nguyen et al., 2015; Njana et al., 2013; Soltani et al., 2012; Torres, Günter, Acevedo-Cabra, & Knoke, 2018). Thus, to engage in different livelihood activities, households use different combinations of livelihood capitals, which in turn, affects livelihood strategies, and deforestation and forest degradation, hence impacting the achievement of sustainable livelihood outcomes (Hosonuma et al., 2012; Miles et al., 2006; Twongyirwe, Bithell, & Richards, 2018). Though the SL approach broadly defines livelihood outcomes to encompass all aspects of poverty reduction and environmental sustainability (Ashley & Carney, 1999; Scoones, 1998), we narrowly define sustainable livelihood outcomes to mean improved rural livelihoods and reduced deforestation and forest degradation.

This research focuses on household-level attributes and contextual factors, which are merged to imply “household-level factors”, deforestation and forest degradation, and their implication on the achievement (or not) of sustainable livelihoods outcomes (Figure 1). Analysing household-level attributes and context-specific factors, deforestation and forest degradation and, examining their implication for livelihoods is critical for understanding the importance of context and interactions at the household scale (Call et al., 2017; De Sherbinin et al., 2008). Moreover, a better understanding of these linkages can be relevant for policies and programmes aiming to improve rural livelihoods and conserving forests, especially in the tropical dry forest areas where forest use and management is intertwined with people’s livelihoods (A. Ali & Rahut, 2018; Angelsen et al., 2014; Call et al., 2017; Dokken & Angelsen, 2015; Duguma et al., 2019; Twongyirwe et al., 2018; Van Khuc, Tran, Meyfroidt, & Paschke, 2018).

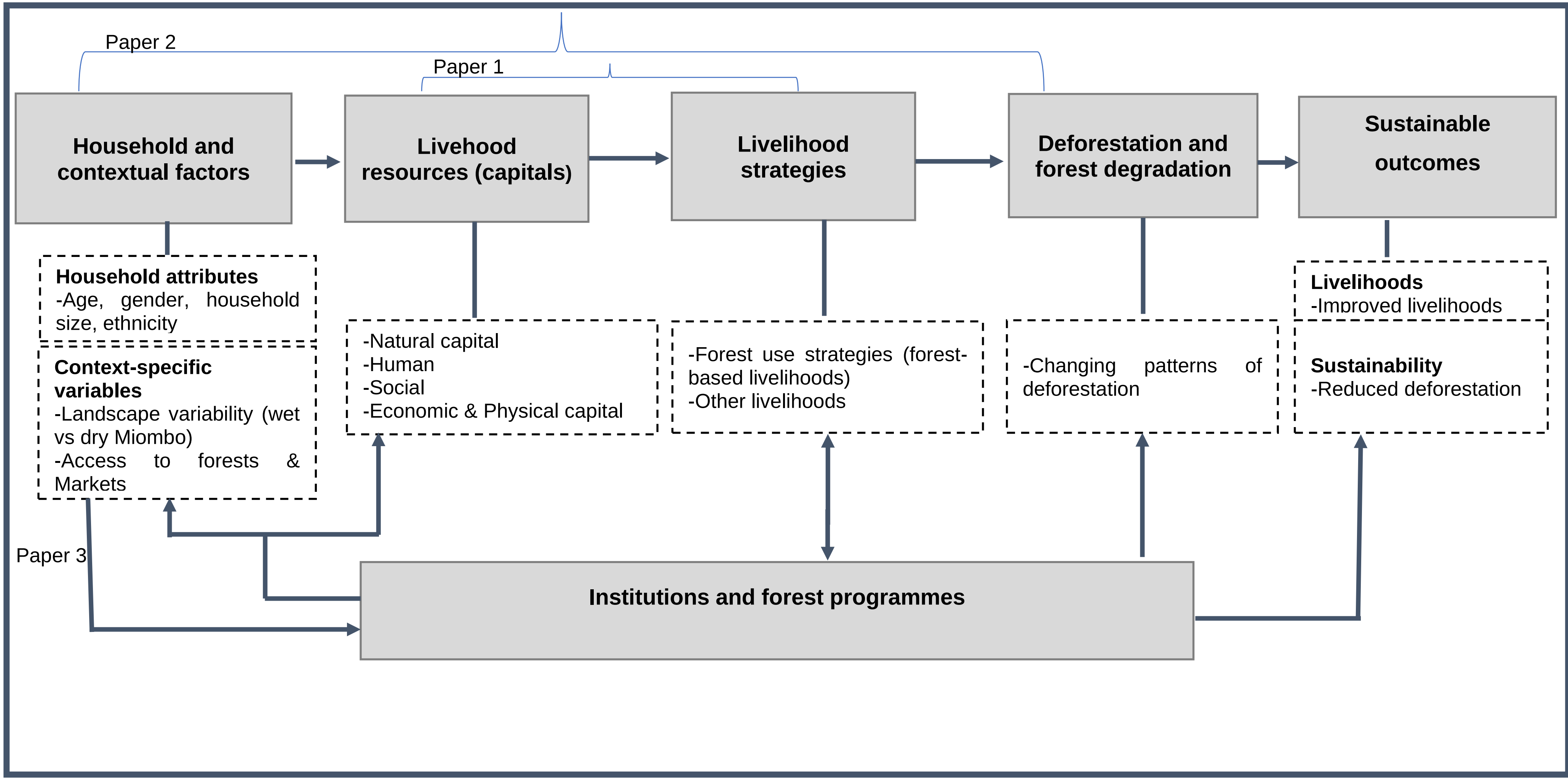

Figure 1. A conceptual framework showing the connection between household and contextual factors, livelihood strategies, deforestation, and forest degradation—*source:* Adapted and modified from Scoones (1998).

1.2. Objectives and hypotheses

1.2.1. Overall objective

This research aims to understand better the relationships between household-level attributes and contextual factors, deforestation and forest degradation, and their implications for livelihoods by using econometric models on smallholder households in Zambia's Miombo forest landscapes.

1.2.2. Specific objectives

1. To understand forest products' roles in household forest use strategies and evaluate the factors that affect forest use strategies and related forest income, focusing on the five livelihood capitals: natural capital, human capital, social capital, and economic and physical capital in the Miombo forest landscapes in the Copperbelt Province.
2. To understand the spatial patterns of household deforestation and examine the effects of household-level attributes and agricultural land use on deforestation patterns along the Miombo forest transition gradient in Zambia.
3. To examine the impact of socio-demographic and economic attributes, access to forest resources and markets (location factors) on household's participation in forest support programmes in the Miombo forest landscapes in Zambia.

1.2.3. Hypotheses

1. (a) Forest products' role in household's forest use strategies vary in the Miombo forest landscapes.
   (b) Livelihood capitals differently influence forest use strategies (Babulo et al., 2008; Nguyen et al., 2015).
2. (a) Household-level causes of deforestation vary regionally across the forest landscapes (Etter et al., 2006; Twongyirwe et al., 2018; VanWey, D'Antona, & Brondízio, 2007).
   (b) Deforestation follows a consistent pattern along forest transition. High deforestation patterns are triggered by commercial crop production at close distance categories from households in the early transition phase (stage 1). In mid to late transition phases (stage 2 and 3), high deforestation associated with increased crop incomes is expected both at close distance and remote distance from households; this is because

deforestation accumulates over time (Angelsen, 2007; Schielein & Börner, 2018; von Thünen, 1826).

3. Household-level factors affect participation in forest support programmes in different ways (Baynes, Herbohn, Smith, Fisher, & Bray, 2015; Coulibaly-Lingani, Savadogo, Tigabu, & Oden, 2011; Dolisca, Carter, McDaniel, Shannon, & Jolly, 2006).

1.3. The publications that constitute the basis of this research

The three papers that form this thesis's basis provide a better understanding of household and contextual factors, forest livelihood strategies and their impact on deforestation and forest degradation, and forest support programmes.

Table 1. The publications that makeup this thesis.

List of publication	Summary	Division of labour
Kazungu, M., Zhunusova, E., Yang, A.L., Kabwe, G., Gumbo, D.J., Günter, S., (2020). Forest use strategies and their determinants among rural households in the Miombo woodlands of the Copperbelt Province, Zambia. Forest *Policy and Economics* 111, 102078. https://doi.org/10.1016/j.forpol.2019.102078	This paper examines the roles of forest products in the households' forest use strategies and analysis factors associated with each forest use strategy choice.	MK, EZ, ALY, GK, DG, SG
Kazungu, M., Ferrer Velasco, R., Zhunusova, E., Lippe, M., Kabwe, G., Gumbo, D. J., & Günter, S. (2021). Effects of household-level attributes and agricultural land-use on deforestation patterns along a forest transition gradient in the Miombo landscapes, Zambia. *Ecological Economics,* 186, 107070. doi:https://doi.org/10.1016/j.ecolecon.2021.107070	This paper examines household-level attributes and agricultural land-use on deforestation patterns along a forest transition gradient. The paper applies a land allocation theory and estimates the impact using the fractional probit models.	MK, RF, EZ, ML, GK., DG, SG
Kazungu, M., Zhunusova, E., Kabwe, G., Günter, S., (2021). Household-Level Determinants of Participation in Forest Support Programmes in the Miombo Landscapes, Zambia. *Sustainability* 13, no.5: 2713. https://doi.org/10.3390/su13052713	This paper examines the household-level factors that affect participation in forest support programmes.	MK, EZ, GK, SG

MK: Moses Kazungu; RF: Ruben Ferrer Velasco; EZ: Eliza Zhunusova; ALY: Anastasia Lucy Yang; ML: Melvin Lippe; GK: Gillian Kabwe; DG: Davison Gumbo; SG: Sven Günter

2. State of the art

This section describes current research about livelihoods, forest resources, deforestation and forest degradation in the tropical and subtropical regions. In addition, this section looks at the forest resources in tropical areas and their contribution to forest use strategies. The study describes deforestation and forest degradation and their causes while highlighting shortcomings in the previous research. Lastly, the section concludes by describing the spatial distribution of agricultural land use across distances from the settlements and along the forest transition.

2.1. Livelihoods, forests, and deforestation and forest degradation

This study tackles two problems; deforestation and forest degradation and poverty. Forests cover about 4 billion hectares globally, nearly one-third of the world's land (FAO, 2020a). In 2020, more than half (56%) of the world's forests were located in tropical and subtropical regions, covering about 2 billion hectares (FAO, 2020a). Of this, the tropical dry forests cover nearly half (42%) of the tropical and subtropical forests (Hasnat & Hossain, 2020; Murphy & Lugo, 1986) and provide livelihoods to some of the world poorest people (Angelsen et al., 2014). However, the tropical dry forests are the most understudied forest ecosystems yet are highly disturbed by human and natural causes (Blackie et al., 2014; Miles et al., 2006; Schröder et al., 2021).

Despite declining global deforestation rates, deforestation rates have remained high in the tropical dry forest regions (FAO, 2020b; Keenan et al., 2015; Poker & MacDicken, 2016). Between 1990–2020, it is estimated that 420 million hectares of forests were lost through deforestation, of which 90% of deforestation occurred in tropical areas (FAO, 2020b). Deforestation rates in tropical regions averaged 9.3 million hectares per year in 2015–2020. Africa, in particular, had the highest annual rate of deforestation averaging 4.4 million hectares (FAO, 2020b). Deforestation was mainly driven by agricultural activities' expansion (Gibbs et al., 2010; Poker & MacDicken, 2016). Simultaneously, forest degradation was caused primarily by firewood extraction and charcoal production (Hosonuma et al., 2012; Kissinger, Herold, & De Sy, 2012).

The continued forest loss threatens a wide range of forest goods and services that are essential for human well-being, such as forest foods and ecosystem services supporting agriculture production and increased risks of drought and floods (Miles et al., 2006). Globally, forests provide livelihoods to nearly 1 billion people living in and near forests. In the tropical dry forest areas, forests contribution is recorded to be as high as that of crops (Angelsen 2014). The Miombo woodlands, which is the largest dry forest formation in Africa, is suggested to support more than 100 million people by providing subsistence and cash incomes (Byers, 2001; Dewees et al., 2010; Njana et al., 2013). Additionally, the Miombo supports household energy needs through firewood extraction and charcoal production (Jones et al., 2016; Tembo et al., 2015; Zulu & Richardson, 2013). Furthermore, the Miombo provides a wide range of ecosystem services, thus playing a vital role in carbon sequestration and biodiversity conservation (Frost, 1996); (see also Hasnat and Hossain (2020); Miles et al. (2006)). Therefore, it becomes essential to understand the relationship between livelihoods, forests, deforestation, and forest degradation to achieve sustainable rural development.

Studies have revealed that the causes of deforestation are multiple and consist of direct and underlying causes (Angelsen & Kaimowitz, 1999; Armenteras, Espelta, Rodríguez, & Retana, 2017; Geist & Lambin, 2002). The direct causes include forest products extraction (forest livelihoods), cropland expansion, infrastructure development and mines extraction (Armenteras et al., 2017; Hosonuma et al., 2012). And the underlying causes are mainly contextual and household-related processes such as socio-demographic attributes, economic aspects and access to forest and markets (Babigumira et al., 2014; Call et al., 2017). These studies mostly agree that causes of deforestation and forest degradation interact in multiple and complex ways and, as such, differently affecting deforestation and forest degradation patterns. However, despite past interests in understanding the causes of deforestation and forest degradation, the analysis of people-environment interactions in the context of sustainable rural development remains under-researched. Taking the case for Miombo forest landscapes, we use livelihood theories and the SL approach to understand how multiple and complex connections between household-level attributes, contextual factors, and deforestation and forest degradation can lead to (or not) achieving sustainable rural development.

Although Miombo woodlands provide various benefits to households, they are primarily recognised for supporting households' subsistence and cash income needs (Kalaba et al., 2013a; Kalaba, Quinn, & Dougill, 2013b; Njana et al., 2013). The subsistence needs are derived from the use of unprocessed forest products, mainly firewood and forest foods; at the same time, cash income is primarily generated from processed forest products, mainly charcoal production (C. B. Jumbe et al., 2008; Njana et al., 2013; Smith et al., 2017). Besides, the Miombo woodlands provide households with land for agricultural fallow and cropland expansion (Jew, Dougill, & Sallu, 2017; D. Phiri et al., 2019b). Past studies recognise that forest resources extraction and cropland expansion are the leading causes of deforestation across the Miombo and Africa's dry forest regions (Hosonuma et al., 2012; Rudel, 2013). This reveals that forest destruction and unstainable use of forest resources are related to people's rational actions in tropical dry forests. Hence, it is critical to better understand the linkages between household-level attributes, contextual factors, and deforestation and forest degradation, all of which can have consequences on livelihoods.

2.2. Forest use strategies

In the tropical and subtropical regions, forest resources provide multiple benefits, including forest goods and ecosystem services supporting household livelihoods (Sunderlin et al., 2005; Vedeld et al., 2007). The most important forest products that households harvest include firewood, wood for charcoal production, poles for construction, and forest foods (Adhikari et al., 2004; Angelsen et al., 2014). These products are consumed either in the raw form (unprocessed) or processed or both. Unprocessed forest products mainly include firewood and forest foods consumed at the household (subsistence) (N. Ali, Hu, & Hussain, 2020; Kalaba et al., 2013a; Sardeshpande & Shackleton, 2020). On the other hand, charcoal production is the most processed forest product, mainly sold to generate household income (Jones et al., 2016; Khundi, Jagger, Shively, & Sserunkuuma, 2011; Smith et al., 2017). In many developing countries, especially in sub-Saharan Africa, more than 80% of urban households use charcoal for energy (Djoudi et al., 2015; Kambewa, 2007; Zulu & Richardson, 2013). For example, in Zambia, nearly half (44%) of urban households use charcoal for cooking (Tembo et al., 2015), in Malawi, about 90% of urban households rely on charcoal energy (Charles Jumbe & Angelsen, 2011; Kambewa, 2007), and in Uganda charcoal use in highly ingrained in household cooking processes (Khundi et al., 2011; Nabukalu & Gieré, 2019).

Past studies on livelihood and forests suggest that forest resources have the potential to lift households out of poverty by equalising the poor and most affluent households moreover cushions households in times of crisis by providing safety net roles (Angelsen et al., 2014; Sunderlin et al., 2005; Wunder, Börner, Shively, & Wyman, 2014). Further, it is suggested that forest resources extraction is often done by both the poor and more affluent households (Dokken & Angelsen, 2015; Kamanga et al., 2009; Shackleton & Shackleton, 2006; Uberhuaga, Smith-Hall, & Helles, 2012). The poor households are mainly suggested to engage in subsistence activities with low-income returns (Angelsen et al., 2014; Charles Jumbe & Angelsen, 2011). Although some households are recorded to engage in cash-generating forest activities, their involvement in commercial forest activities has been shown to decline once they become better off (Ainembabazi, Shively, & Angelsen, 2013; Vedeld et al., 2007). These views indicate that forest resource extraction can only play a limited role in improving the wellbeing of the rural poor because it provides only supplementary roles in households livelihoods (Djoudi et al., 2015).

Despite the benefits of forest resources to households, forest products' role in the household's livelihood strategies remains unknown. Past studies have often tended to conflate forest products with non-forest livelihood activities under a generalised term “livelihood strategies” in households’ livelihood analysis (Babulo et al., 2008; Nguyen et al., 2015; Soltani et al., 2012; Torres et al., 2018). Yet, there are significant differences in forest products' contribution to household livelihood portfolios (N. Ali et al., 2020; C. B. Jumbe et al., 2008; Njana et al., 2013; Vedeld et al., 2007). Distinguishing forest products' contribution to households’ livelihoods helps better understand how forest use strategies can be associated with rural income growth and household's wellbeing. This can be useful for researchers and policymakers who aim to improve rural livelihoods while preserving forests (Angelsen et al., 2014).

2.3. Deforestation and forest degradation

Deforestation is mainly defined as the conversion of forests to agricultural land (FAO, 2020b), and forest degradation is the reduction in forest biomass through the unsustainable harvest of forest resources and land use practices (McNicol, Ryan, & Mitchard, 2018). While deforestation and forest degradation rates have substantially decreased over the last three decades, in the tropical regions, the rates remain high (FAO, 2020b). For example, from 2015 to 2020, Africa had the highest deforestation rate, estimated at 4.41 million hectares per year (ha yr^{-1}), followed by South America (2.96 million ha yr^{-1}) and Asia, 2.24 million ha yr^{-1} (FAO, 2020b). The Eastern and Southern Africa region with the Miombo vegetation type had the highest deforestation rates, estimated at 2.20 million ha yr^{-1} compared to the Northern Africa, Western and Central Africa (FAO, 2020b) (see also Bodart et al., 2013).

Across sub-Saharan Africa, deforestation rates remain generally high, 2% yr^{-1}, despite varying deforestation trends across countries (Bodart et al., 2013; McNicol et al., 2018). For example, Zambia, 3.1% yr^{-1} (D. Phiri, Morgenroth, & Xu, 2019a), Mozambique, 2.8% yr^{-1} (C. M. Ryan, Berry, & Joshi, 2014) and Malawi, 1– 4.7% yr^{-1} (Bone, Parks, Hudson, Tsirinzeni, & Willcock, 2017; McNicol et al., 2018). The difference in the deforestation rates across many countries is partly due to estimation methods—previous deforestation studies have often sought to estimate deforestation based on remotely sensed data (Stan & Sanchez-Azofeifa, 2019). Remotely sensed data is sensitive to spatial variability of deforestation, such as the size of land cleared, which may be too small for tree cover to be recognised in a resolution (Corbera, Estrada, & Brown, 2010; Mayes, Mustard, & Melillo, 2015).

The causes of deforestation and forest degradation largely remain similar in most tropical and subtropical regions, and Africa in particular (Hosonuma et al., 2012; Rudel, 2013). These factors mainly include agricultural land expansion, population pressure, woodfuel and timber extraction (Kissinger et al., 2012). Across the tropical and subtropical regions, agricultural land expansion, mainly subsistence and commercial crop production, have been recognised to drive more than 80% deforestation (Gibbs et al., 2010). In Africa alone, subsistence agriculture is recorded to drive about 40% of deforestation, while in Latin America, the leading cause of deforestation is recorded to be mainly commercial agriculture (Hosonuma et al., 2012). On the other hand, forest degradation is caused by firewood extraction, charcoal production, timber harvesting, and logging (Kissinger et al., 2012). Woodfuel extraction accounts for nearly half of forest degradation in Africa (Hosonuma et al., 2012; Poker & MacDicken, 2016).

Hence, deforestation and forest degradation are a threat to human life because forests support millions of households who depend on forest resources (Blackie et al., 2014; Chao, 2012; Hasnat & Hossain, 2020). Further, it is recorded that tropical and subtropical dry forests are a rich reservoir of biodiversity and critical ecosystem services (Foley et al., 2007; Miles et al., 2006). Therefore, tropical and subtropical forests provide households with a broad range of goods and services. To understand deforestation and forest degradation and their causes in the tropical landscapes, it thus becomes essential to integrate household surveys and remotely sensed data (Gibbs, Brown, Niles, & Foley, 2007). This is especially important for researchers and policymakers seeking a better understanding of enhancing livelihood benefits from forests while simultaneously conserving the forests (Börner et al., 2016; Börner, Schulz, Wunder, & Pfaff, 2020; Miles et al., 2006).

2.4. Agricultural land use and forest transition

Deforestation pressures from agricultural land use often vary across landscapes. The von Thünen (1826) suggests that land allocation to crop production can be affected by distances to the markets (settlements). Following the von Thünen approach, recent studies have sought to examine how spatial distribution of agricultural land use can relate to forest cover changes and forest transition (Angelsen, 2007; Schielein & Börner, 2018).

The forest transition describes the process of forest cover changes over time (Mather, 1992). It explains how economic development processes such as road network expansion, urbanisation and rural structural differences can affect forest cover and agricultural land use (Rudel et al., 2005). As such, the forest transition describes stages of declines and increases in forest cover such as high forest cover and low deforestation (phase 1), increased forest cover and accelerated deforestation (phase 2), low forest cover and low deforestation (phase 3), and reforestation (phase 4) (Mather & Needle, 1998; Rudel et al., 2005).

In the early phase of forest transition, primary forests are predominantly lost at close distances to settlements through the conversion to agricultural uses; this is because of higher returns from agricultural land use than when the land remained as forests (Angelsen, 2007). Similarly, in the mid forest transition (mainly phase 2), high demand for forest products and proximity to markets drives higher deforestation in close distance and remote distances from settlements. Eventually, forest scarcity raises the value of forest resources, exacerbating deforestation in both close and remote areas while also increasing secondary forest management (Angelsen, 2007; Barbier, Burgess, & Grainger, 2010). The spatial distribution of land use suggests that economic costs associated with agricultural production can influence land use patterns, which differently affects forest cover along the forest transition (Barbier et al., 2010).

Despite previous interest in explaining land use changes and forest transitions in developing countries, this concept has not been empirically tested to explain agricultural land uses (Angelsen, 2007; Köthke, Leischner, & Elsasser, 2013; Rudel et al., 2005). Most developing countries have experienced sustained infrastructure development, population growth, urbanization, and land use transformations in recent decades (Gibbs et al., 2010; Zhang, 2016), implying the existence of a forest transition within a country or at the continental level (Köthke et al., 2013; Rudel et al., 2005). Thus, cropland distribution, proximity to markets, and deforestation and forest degradation can affect forest cover changes differently but vary across landscapes and along the forest transition (Angelsen, 2007; Leblois, Damette, & Wolfersberger, 2017). Understanding the relationship between agricultural land use, mainly crop productivity, and distances to the population centres are important for policies seeking to harmonise rural land use and conservation approaches (Schielein & Börner, 2018). Further, examining variations in cropland allocation across the forest transition is important for researchers seeking to better understand the causes of deforestation and forest degradation across different landscapes with different forest cover levels (Etter et al., 2006).

3. Material and methods

3.1. Study area

This study was conducted in three provinces of the North-Western, Copperbelt and the Eastern Province of Zambia (Figure 2). These provinces were chosen because they have similar vegetation types — the Miombo ecosystem (E. Chidumayo, 1987). In the Miombo woodland areas of Zambia, forest resources use forms a significant part of households' livelihood activities (Emmanuel Ngulube Chidumayo, 2019; C. B. Jumbe et al., 2008; Kalinda, Bwalya, Munkosha, & Siampale, 2013; Mulenga et al., 2014). Moreover, these provinces have varying forest cover levels (Hansen et al., 2013; Shakacite, 2016). The North-Western Province has about 75% of its total areas under forest cover, Copperbelt, 64% and the Eastern Province have the lowest forest cover representing approximately 17.5% of its total land cover (Hansen et al., 2013). The remaining forest cover variations across different provinces demonstrate that the North-Western Province, Copperbelt, and the Eastern Province represent the forest transition's three stages (Figure 2).

Furthermore, the study provinces have varying biophysical backgrounds; for example, the North-Western and Copperbelt Provinces receive annual rainfall from 1000 to 1500 mm. In contrast, the Eastern Province receives an average yearly rainfall of less than 1000 mm (Emmanuel Ngulube Chidumayo, 2019). Thus, the three provinces selected in the study represent both wet and dry Miombo vegetation (E. Chidumayo, 1987; Emmanuel Ngulube Chidumayo, 2019). The households in these provinces are mainly dependent on land-based activities. These livelihood activities are mostly extraction of firewood, poles and fibres for construction and forest foods (unprocessed forest products); charcoal production (main processed forest product); agricultural activities such as crop production and livestock; and non-farm (self-employment, wages, and remittances) activities (Table 2).

In the North-Western Province, households mainly engage in crop production and extract forest products for subsistence and cash needs (Gumbo et al., 2013; Shakacite, 2016). While in the Copperbelt Province, crop production, extraction of unprocessed forest products, and charcoal production constitute most households' main livelihoods (Kalaba et al., 2013a). And the Eastern Province, which is mainly agrarian, is dominated by smallholder producers engaged in crop production for subsistence and cash generation (Tembo & Sitko, 2013). However, some households are also involved in charcoal production, which supplements their income needs (Gumbo et al., 2013).

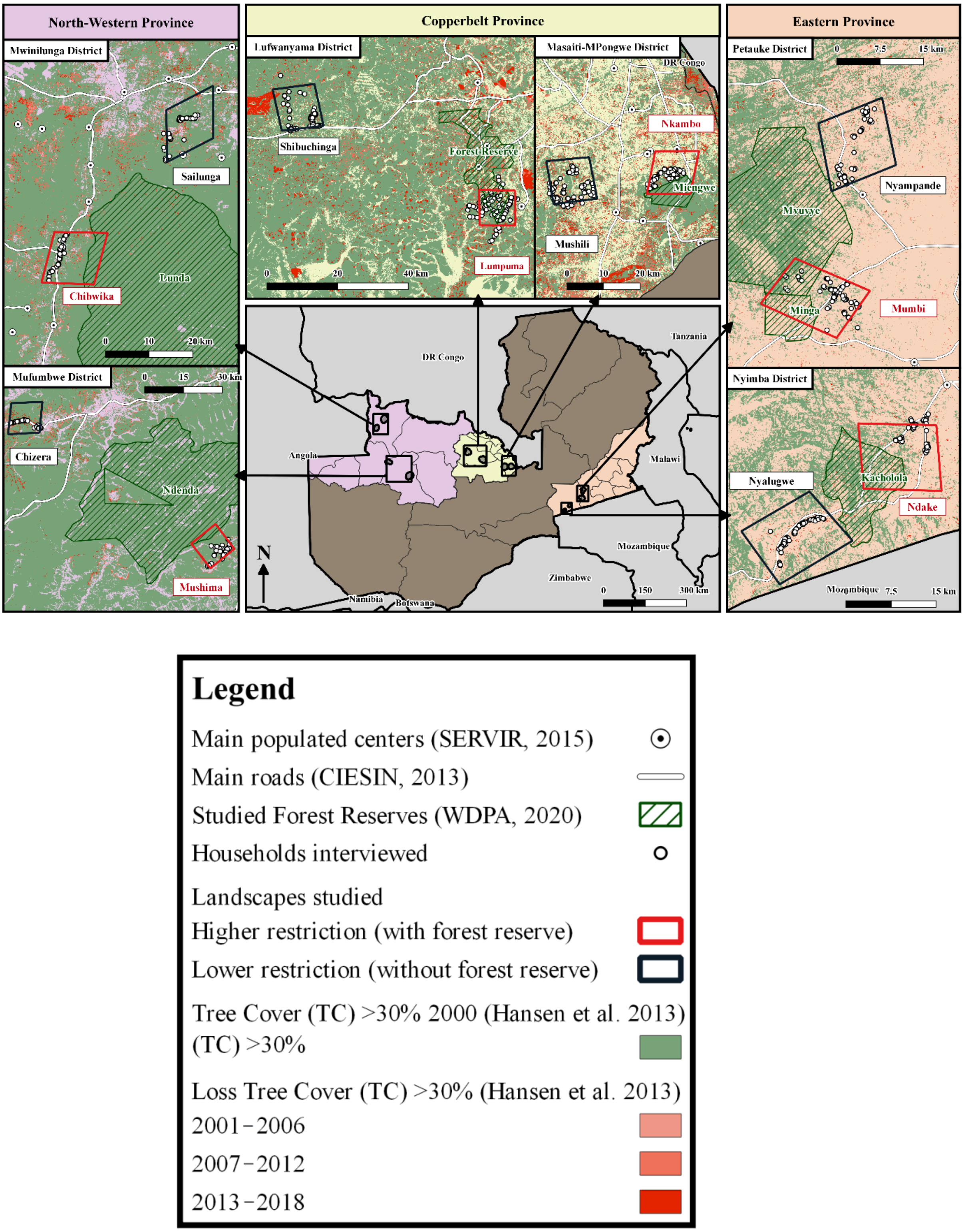

Figure 2. Map of Zambia showing the study provinces, landscapes and forest regimes. *Sources:* Adapted from Kazungu, Zhunusova, Kabwe, and Günter (2021).

3.2. Data sources and processing

3.2.1. Sample design and household Surveys

A random sample that resulted in selecting 1200 households located in 37 villages across the North-Western Provinces, the Copperbelt and the Eastern Province of Zambia was conducted. Data was collected through face-to-face interviews using a structured questionnaire, and the interviews lasted close to one hour and thirty minutes (1:30 hrs). In each region, the interviews were conducted by trained assistants who were conversant with the local dialects (see Kazungu et al. (2020) and Nansikombi, Fischer, Kabwe, and Günter (2020) for the description of the methods for selecting households and landscapes). Based on the procedures for assessing livelihoods in the forest landscapes (Angelsen, 2011), we captured information related to household-level information such as age, household size, gender, ethnicity and educational levels (socio-demographic); economic attributes (i.e., land use, forest products, agriculture, off-farm and non-farm activities), and contextual attributes such as access to forests and distances to markets (roads and village centres) (Table 2).

Further, we use self-reported quantities and village-level prices to estimate household quantities consumed and sold. We used village-level prices reported during the price survey for certain products, mainly forest products that were not traded (Kazungu et al., 2020). The agricultural produce and forest products, and incomes were calculated as annual values. Income was calculated as net values after subtracting costs (Cavendish, 2002). Finally, after removing plausible surveys, this research analyses a subset of 412 households from the Copperbelt Province and 1123 households from all three study provinces (Table 2).

Table 2. Household-level and contextual attributes in the study provinces of Zambia (adapted from Kazungu, Ferrer Velasco, et al., 2021).

Variables	Provinces			Whole sample (n=1123)
	North-Western (n=374)	Copperbelt (n=394)	Eastern (n=355)	
	Mean (SD)[a]	Mean (SD)	Mean (SD)	Mean (SD)
Household-level attributes				
Socio-demographic				
Male-headed household, 1=Yes; 0=No	81.3%	88.8%	75.5%	82.1%
Head of household attained above primary education, 1= Yes; 0=No	29.4%	24.6%	17.2%	23.9%
Age of household head, years	43.7 (15.0)	45.0 (13.9)	46.2 (14.9)	44.9 (14.6)
Household size, number of members	6.5 (2.5)	5.9 (2.5)	5.8 (2.3)	6.0 (2.5)
Household size, adult equivalent units (AEU)	4.9 (2.0)	4.5 (1.9)	4.6 (1.9)	4.7 (1.9)
Duration of residence, years	14.9 (12.0)	16.0 (13.6)	18.0 (18.2)	16.3 (14.8)
Ethnicity, North-Western-Lunda; Copperbelt, Lamba; Eastern, Nsenga	62.0%	49.2%	96.3%	NA
Economic				
The total size of the patch of land-use, ha	3.0 (3.5)	4.7 (8.4)	2.0 (1.6)	3.3 (5.5)
Livestock, tropical livestock unit (TLU)	0.5 (1.2)	1.4 (2.4)	1.1 (1.7)	1.0 (1.8)
Total household income, Zambian kwacha (ZMW)[b]	9253.4 (6579.7)	13528.7 (13841.2)	5913.8 (3653.8)	9697.7 (9770.2)
Contextual attributes				
Household distance to the village centre, walking time (minutes)	26.1 (28.0)	61.3 (68.2)	40.6 (49.4)	43.0 (53.6)
Household distance to the main road, walking time (minutes)	89.6 (153.3)	62.2 (74.9)	10.5 (22.7)	55.0 (104.8)
Household had access to permanent road, 1=Yes; 0= No	51.3%	32.7%	47.9%	43.7%
Landscape has forest reserve; 1=Yes, 0=No	47.3%	49.0%	52.1%	49.4%
Landscape in wet miombo; 1= Yes, 0=No	NA	NA	NA	68.4%
Patches of land-use in the close-distance category, per cent of households	8.9%	11.0%	8.0%	28.0%
Patches of land-use in the medium-distance category, per cent of households	18.8%	17.2%	18.5%	54.5%
Patches of land-use in the remote-distance category, per cent of households	5.6%	6.9%	5.1%	17.5%

[a]Standard deviation (SD) in parentheses.
[b]Income is calculated as net incomes in Zambian Kwacha (ZMW) (i.e., revenue minus the production cost).

3.2.2. Estimating the volume of firewood harvested and charcoal produced by households

The UN Food and Agriculture Organisation (FAO) defines woodfuel broadly to include firewood, charcoal and other agrofuels derived directly or indirectly from trees and shrubs grown in forests and non-forest lands (FAO, 2004). We define woodfuel as directly collected solid firewood and charcoal produced from natural forests. To estimate the quantity of woodfuel extracted by the households, we measured the actual dry weights in kilograms (kgs) of firewood headload bundle and charcoal produced (i.e., 50-bag kg +ball pen of charcoal) in different villages (Kazungu et al., 2020). We applied different conversion factors for each woodfuel product to convert the quantities measured to volumes. For charcoal, we used a conversion factor of 9m^3 per tonne for every 32 kg of charcoal produced (Emmanuel N. Chidumayo, 1993; FAO, 1987) and for firewood, we used 0.33m^3 per tonne for every 23 kg headload of firewood (Openshaw, 1983).

3.2.3. Calculating deforestation

Deforestation was calculated in areas of households' influence. We used average distances that households walked to patches of own land-use to estimate distance categories, reflecting close-distance, medium-distance, and remote-distance categories. The distance categories provided the basis for establishing thirty-six (36) spatial units. These spatial units represent areas of households' influence, which can occur either through crop cultivation or forest product extraction (Kazungu, Ferrer Velasco, et al., 2021).

To calculate deforestation in the 36 spatial units, we used Hansen et al. (2013) forest cover data. Hansen et al. (2013) data present tree cover loss as the removal of tree cover, which can be due to fire, mechanical harvesting, disease or the presence of storms. However, it is also important to note that tree cover loss can occur due to variations in ecological conditions (Holmgren, Hirota, Van Nes, & Scheffer, 2013). Tree cover (the density of the tree canopy that covers the surface of the land) is characterised by trees that can be in the form of natural forests or plantations. We defined forests as areas with at least 30% tree cover (TC 30%). This definition was arrived at after visual interpretation of satellite photos and ground-truthing in our study landscapes.

Further, deforestation is defined as a loss of tree cover (< 30% criterion) from 2013 to 2018 compared to the reference pixel in 2000 (Hansen et al., 2013). We considered the period 2013–2018 in estimating deforestation because this timeframe is close to the 2017–2019 period in which household data were collected for this research. In the study areas, about 66% of households reported having acquired land in 2000. Hence, most of the land-use changes in our sample landscapes are the consequence of household characteristics (Kazungu, Ferrer Velasco, et al., 2021).

3.3. Analytical approaches

To examine the impact of household and contextual factors, including livelihood capitals on forest livelihoods, deforestation and forest degradation, and their implications for livelihoods, we used different econometric models on smallholder households from the Miombo landscapes Zambia. In the first instance, we explain how we used cluster methods to establish forest use strategies and describe the multinomial regression used to assess livelihood capitals that influence different forest use choices (Kazungu et al., 2020). Secondly, we described how household deforestation strata were established and gave a short description of the modelling approach; the generalised ordered logistic regression model was used to assess causes of deforestation (Kazungu, Ferrer Velasco, et al., 2021). Lastly, the study describes the logistic regression model used to examine how household and contextual factors can influence participation in FS programmes (Kazungu, Zhunusova, et al., 2021).

3.3.1. Cluster analysis for determining forest use strategies

We used cluster analysis on forest income to determine the distinct class which reflect the households' forest-based strategy choices. Clustering is a technique for developing meaningful subgroups by classifying a sample of entities into mutually exclusive small numbers based on some similarities, in our case, income (Hair, Black, Babin, Anderson, & Tatham, 1998). The optimal number of clusters was determined by conducting a k-mean clustering technique (Hastie, Tibshirani, Friedman, & Franklin, 2005). The k-means clustering method is important for data whose cluster is unknown. As such, several k-means solutions with a different number of groups k $(k = 1,2 \ldots, K)$ can be computed and compared (Makles, 2012). Additionally, we conducted the ANOVA test to check whether there were significant variations in the income means between groups.

3.3.2. Estimating determinants of forest use strategies

Following the cluster analysis, three categories were identified that represent households' forest use strategy choices. In analysing data whose dependent variable is categorical, yet the categories cannot be perfectly separated, Starkweather and Moske (2011) suggest using multinomial models. Specifically, we use a multinomial logistic regression (Wooldridge, 2010). The theoretical model multinomial logistic regression model takes the form as applied by Dehghani Pour, Barati, Azadi, and Scheffran (2018):

$$\eta_{ij} = \frac{\exp\,(X'_j\,\beta_j)}{\sum_{i=1}^{m} \exp\,(X'_i\,\beta_i)},\ j = 1,2 \ldots, m \qquad [1]$$

Where η_{ij} is the model for the probability of household that shows that household i chooses a livelihood strategy j from m strategies, X_i is the vector for the explanatory variables such as distances to forestlands, household composition, age of household, and non-farm incomes. These explanatory variables are associated with the i^{th} household, while β_j =0 represents the baseline. Thus the coefficients are interpreted with respect to the baseline strategy and estimated by the maximum likelihood method (Wooldridge, 2010).

3.3.3. Determining the causes of deforestation

We created three categorical variables that contain categories corresponding to low deforestation, medium deforestation and high deforestation. These deforestation strata were created using the 'xtile' command in Stata (Stata.com). These strata reflect low deforestation, medium deforestation and high deforestation. We used ANOVA to compare the relationship between deforestation and distances within and across treatments (Kazungu, Ferrer Velasco, et al., 2021).

Furthermore, since our dependent variable is categorical and ordered, we use ordered models to estimate household variables' impact (O'Connell, 2006). However, the data should meet the proportionality assumption to apply the ordered logistic or probit model (Fullerton, 2009). This assumption states that the relationship between each pair of outcome groups (deforestation levels) is the same. Thus, there can only be one set of coefficients, i.e., one model for each region. However, our data did not meet this assumption, so we used a generalised ordered logistic (gologit) regression (Williams, 2006).

The gologit was specifically chosen because of its ability to relax the proportionality assumption (i.e., parallel line). Moreover, it can be modelled so that the interpretation is similar to the ordered logistic regression. Hence, we used the gologit regression with the parallel line option, which allows the estimation of results identical to the ordered logistic model (Eqn.2). The interpretation of gologit regression results is similar to ordered logistic regression. Thus, the generalised ordered logistic regression models take the form (Williams, 2006):

$$P(Y_i > j) = \frac{exp(\alpha_j + X_i\beta_j)}{1+[exp(\alpha_j + X_i\beta_j)]},\ j = 1,2,\dots,M-1 \quad [2]$$

Where M is the number of categories, P is the probability, j is the deforestation level, P is the probability, j is the deforestation level (Low, Medium, & High), α_j is a parameter that represents the thresholds or cut points, β_j is a vector of unknown parameters to be estimated.

Furthermore, X_i is a vector for explanatory variables for household i, which includes socio-demographic attributes such age of household head, gender, education level, household size, residence duration, ethnicity; economic attributes including, land size, livestock, incomes (forest, crops, fish capture, off-farm and non-farm), and access factors such as distances to forests and markets, landscape dummy and interactions (i.e., crop productivity and distance categories).

Additionally, we estimate the marginal effects since the coefficients of the parameters cannot be directly interpreted. The marginal results indicate the change in the probability of observing a specific outcome of Y when an explanatory variable increases by one unit for continuous variables or a discrete change from 0 to 1 for dummy variables. Thus, a significant positive coefficient value means that higher values of the independent variable make the dependent variable more likely. Lastly, the parameters (β) are estimated using the maximum likelihood estimation technique.

3.3.4. Estimating the determinants of participation in forest support programmes

Participation in Forest Support (FS) programme means a household registers with the programmes and successfully participates in their activities. While non-participation implies, households did not participate in FS programme activities. Thus, the dependent variable, participation in FS programmes, is a binary outcome that contains one (1) for households that registered and successfully participated in FS programmes and zero (0) for those not participating (Kazungu, Zhunusova, et al., 2021). A binary outcome is best explained with binary choice models (Verbeek, 2008). This research uses explicitly a logistic regression model described by Hosmer Jr, Lemeshow, and Sturdivant (2013).
The binary outcome for participation in FS programmes takes the form:

$$\mathrm{Y_i} = 1 \text{ if } Y^* = \beta_1 X_\mathrm{i} + \varepsilon_\mathrm{i} > 0 \qquad [3]$$

$$= 0 \text{ if otherwise}$$

Where Y is the dependent variable, β is a vector of unknown parameters (coefficients) to be estimated. And X is the vector of explanatory variables, such as age of the head of household, gender, education, household size, land size, incomes (crop, forest, non-farm incomes), distance to land, markets and restricted access to forest resources. The term ε is the error expressing observations' deviations from the conditional mean. i represents the observations $(\mathrm{i} = 1,2,3 \dots)$. The subscript i is suppressed for clarity.

Following Hosmer Jr et al. (2013), the logit model shall be as follows:

$$\mathrm{P(x)} = \frac{e^{\beta_1 \mathrm{X}}}{1+e^{\beta_1 X}} \qquad [4]$$

Where $\mathrm{P(x)}$ represents the conditional mean of y given x, (i.e., $\mathrm{P(y_i = 1|x_i)}$)
Thus, from Eqn. 3, the dependent variable (Y) will be; $Y = \mathrm{P(x)} + \varepsilon$.
Accordingly, if $Y = 1$, then $\varepsilon = 1 - \mathrm{P(x)}$ with a probability of $\mathrm{P(x)}$
And if $Y = 0$, then $\varepsilon = -\mathrm{P(x)}$ with a probability of $[1 - \mathrm{P(x)}]$
Therefore, the conditional distribution of the outcome variable follows a binomial distribution with a mean of zero and variance equal to $\mathrm{P(x)}[1 - \mathrm{P(x)}]$. The parameters for the logistic regression are thus estimated using the maximum likelihood (ML) method.

4. Results and discussion

This chapter summarises the results obtained from the three manuscripts that form the basis for this dissertation thesis. We apply different econometric models to smallholder households to better understand the relationships between household-level attributes, contextual factors, deforestation and forest degradation and their implications for livelihoods. The study's findings form the basis for better understanding the pros and cons of using economic models and household surveys to understand households, forest resources' use, land use change, and sustainable rural development. Hence, researchers and policymakers will better understand the impact of the complex and dynamic households' processes and context-specific attributes on achieving (or not) sustainable rural outcomes (improved livelihoods and reduced deforestation). The results of this research provide science-based support for policy designs and interventions.

4.1. Forest use strategies and their determinants in the Miombo landscapes of Zambia's Copperbelt Province

The main findings of the first publication (Kazungu et al., 2020) were as follows: (1) assessing household income distribution by source in the Copperbelt Province; (2) determining forest use strategies adopted by households in the Copperbelt Miombo landscapes; (3) determining the volumes of firewood extracted and charcoal produced by households; and (4) determining the factors influence different forest use.

4.1.1. Distribution of household income by source in the Copperbelt Province

In the Miombo areas of the Copperbelt Province, rural households engage in different livelihood activities such as forest products extraction, crop production, livestock, fish capture, off-farm and non-farm (self-employment, wages, and remittances) activities (Table 3). The contribution of these livelihood activities to a household's income substantially varies across product lines (Table 3). Forest resources contribute the most (i.e., about 54%) of household income and are consumed as unprocessed or processed products. The unprocessed products mainly include forest foods, firewood, poles for construction and fibres (Kazungu et al., 2020), providing subsistence income. On the other hand, charcoal production was the main processed forest product which mainly was sold to generate household income (see also Jones et al. (2016) and Smith et al. (2017)). This research's findings suggest that even though rural households have a multitude of income sources, the contribution of forest resources to household's income portfolio remain substantial, suggesting the important role of forest products in supporting current consumption (Dokken & Angelsen, 2015; Njana et al., 2013)

Table 3. Distribution of household income by source in the Copperbelt Province (n=412) (adapted and modified from Kazungu et al. 2020).

Income sources (Zambian kwacha) (ZMW)[a]	Mean ±SD	Share of total sample income (%)
Forest income		
Unprocessed forest product income	994±1259	16.7
Processed forest product income	2222±8272	37.4
Subtotal:		**54.1**
Agriculture income		
Crop income	1390±4670	23.4
Livestock income	563±1261	9.5
Fish income	8±26	0.1
Subtotal:		**33.0**
Off-farm and non-farm income		
Off-farm income	39±189	0.7
Self-employment	515±3575	8.7
Remittances income	71±312	1.2
Wage income	133±664	2.3
Subtotal:		**12.9**
Total household income	**5935±11026**	**100**

[a]Income is measured in net value divided by the AEU and is calculated in Zambian Kwacha (ZMW) per capita. At the time of the study, 1 USD = 10.13 ZMW (Bank of Zambia, 2018).

4.1.2. Forest use strategies in the Miombo forest landscapes in the Copperbelt Province

The cluster analysis results reveal that households in the Miombo areas of the Copperbelt Province adopted three forest use strategies, which include specialised charcoal sellers, forest food and charcoal sellers, and pure subsistence-orientated forest users (Table 4). About half of the households in the study areas adopted the pure subsistence-orientated forest users' strategy. Charcoal livelihood strategies consisted of specialised charcoal sellers, 32.3% and forest food and charcoal sellers, 18.2% of households (Table 4). These forest use categories reveal how forest use contributes to households' livelihood strategies and thus underscores the important roles that forest resources play in households' livelihoods (Angelsen et al., 2014; Vedeld et al., 2007). Such categorisation of forest use can provide relevant information for targeted policy actions and programme designs seeking to preserve the forests while simultaneously improving rural livelihoods (Wunder, Angelsen, et al., 2014).

Furthermore, forest incomes across the clusters were statistically distinct (Table 4), indicating that forest resources contribute differently to households' income portfolios (Uberhuaga et al., 2012; Vedeld et al., 2007). Unprocessed forest products mainly provided subsistence income, while on the other hand, forest processed products (specifically charcoal production) generated cash income (Table 4). This finding implies that forest resources are important in supporting household's consumption and providing alternative pathways of generating income (Kalaba et al., 2013b). Thus, forest resources can play significant roles in improving a household's wellbeing (Angelsen et al., 2014; Vedeld et al., 2007). Additional tests (i.e., ANOVA and chi-square (X^2)) indicates that average forest incomes measured vary across clusters, and at least two clusters differ statistically (Table 4). Charcoal livelihood strategies were the most lucrative and earned households higher cash incomes than subsistence-orientated livelihood strategy. This finding confirms part (a) of the first hypothesis: *"Forest products' role in household's forest use strategies vary in the Miombo forest landscapes".*

Overall, our results have shown that most households in the Miombo forest landscapes are still engaged in subsistence forest use and persistently poor (Angelsen et al., 2014; Sunderlin et al., 2005; World Bank, 2018). Conversely, the study shows that charcoal livelihoods are essential sources of rural cash income (Jones et al., 2016; Mwitwa & Makano, 2012; Smith et al., 2017). However, charcoal production is primarily the affluent household domain, but it is considered illegal (GRZ, 2015; Zulu & Richardson, 2013). This study shows that charcoal production can enhance rural household income, but only if it is done in a sustainable and controlled manner (Doggart & Meshack, 2017). Sustainability in charcoal production can be achieved by incorporating methods that improve wood availability while at the same time providing alternative income generation. Such methods can include integrating agroforestry and reforestation in the production systems (Adeniji, Zacchaeus, Ojo, & Adedeji, 2015). The following subsection describes the volumes of charcoal produced and firewood extracted across households in landscapes with and without protected forests and examines factors that affect forest use strategies.

Table 4. Cluster results of forest products' contribution in forest use strategies (adapted from Kazungu et al. 2020).

Variables	Whole sample (n=412)	Clusters			X^2
		Pure subsistence forest users (1) (n=204)	Specialised charcoal sellers (2) (n=133)	Forest food and charcoal sellers (3) (n=75)	
^Y **Absolute forest income**	3216±8833	$745^{2,3***}$ ±940	5784^{1***3} ±13840	5386^{1***2} ±7469	782^{***}
Unprocessed forest products income					
Total income	994±1259	$745^{2,3***}$ ±940	1239^{1***3} ±1378	1237^{1***2} ±1628	42^{***}
Subsistence income	916±1187	678^{2***3*} ±861	1239^{1***3} ±1378	992^{1*2} ±1434	46^{***}
Cash income	78±275	67^{2*3***} ±290	0^{1*3***} ±0	$245^{1,2***}$ ±388	10^{***}
Processed forest products income					
Total income	2222±8272	$0^{2,3***}$ ±0	4545^{1***3} ±13241	4149^{1***2} ±6342	42^{***}
Subsistence income	148±621	$0^{2,3***}$ ±0	249^{1***3} ±844	373^{1***2} ±860	0
Cash income	2074±7801	$0^{2,3***}$ ±0	4296^{1***3} ±12545	3776^{1***2} ±5794	46^{***}

^Y Income values are in net value in AEU per capita and measured in Zambian Kwacha (ZMW). ± is the standard deviation. Superscript numbers show statistically significant differences between each respective cluster with other clusters (ANOVA test); *** significant at 0.01, ** significant at 0.05, and * significant at 0.1 levels. Note that Zambia's international poverty line is considered to be less than 6.4 ZMW per day (World Bank, 2018).

4.1.3. Volumes of firewood extracted and charcoal produced by households

In the Copperbelt Province, households' volume of woodfuel produced differed significantly between landscapes with and without protected areas (Table 5). We found that the per capita consumption of woodfuel in the protected landscapes was $1.61 m^3 yr^{-1} AEU^{-1}$, higher than in non-protected landscapes. Regarding specific woodfuel extraction, we found that the per capita production of charcoal was $6.01 m^3 yr^{-1} AEU^{-1}$, higher than firwood extracted in both landscapes (Table 5).

Our findings partly suggest that restriction in access to and use of forest resources does not affect households extraction tendencies (Jagger, Luckert, Duchelle, Lund, & Sunderlin, 2014), which implies that in rural areas, forest use is intertwined with households livelihood strategies (N. Ali et al., 2020; Angelsen et al., 2014; Njana et al., 2013). Secondly, these outcomes reveal overlapping claims on forest resources and weaknesses in implementing Zambia's forest policies (Kalaba, 2016). Lastly, this finding confirms the previous studies suggesting higher woodfuel dependencies for household energy provision in the sub-Saharan African countries (Djoudi et al., 2015; Poker & MacDicken, 2016; Zulu & Richardson, 2013) and Zambia in particular (Tembo et al., 2015).

Table 5. Volumes of woodfuel extracted in a year by households in the Miombo areas of the Copperbelt Province (adapted from Kazungu et al., 2020).

Description	[1]Average units collected/year/hh (restricted landscape)	Average units collected/year/hh (non-restricted)	[2] Unit	[3]Average kgs/unit	Conversion factor (m^3/t)	[4]Volume m^3/year/hh (restricted landscape)	Volume m^3/year/hh (non-restricted)	[5]Volume m^3/year/AEU (restricted landscape)[a]	[6]Volume m^3/year/AEU (non-restricted)
Firewood	138.9 (CI, 121.7–156.1)	129.4 (CI, 114.4–144.3)	Headload (Bundle)	23±7.98	0.33	1.05	0.98	0.23	0.22
Charcoal	62.9 (CI, 47.7–78.0)	37.9 (CI, 25.4–50.4)	50-bag-kg+'ball pen'	32±3.11	9.00	18.12	10.92	4.03	2.43
Total						**19.17**	**11.90**	**4.26**	**2.65**

1. Confidence interval (CI) is taken at 95%. 2. The local unit is used for measuring forest products in the study area. 3. Random weights of firewood and charcoal were taken at different locations of the study; in total, each product was weighed five times. 4. Volume per cubic metre per year per household (m^3/year/hh) is calculated by multiplying the average unit by average kgs, the result is converted to tonnes and then divided by a conversion factor (e.g., for a restricted landscape we have 138.9*23kg=3194.7kg ➔3194.7kg = 3.1947 t ➔ 3.1947*0.33= 1.054m^3/year/hh). 5, and 6. Cubic volume per year per person (AEU) (i.e., m^3/year/hh), calculated by dividing [4] by household size per AEU (4.5) (Kazungu et al., 2020). N=412.

[a]Note, assuming firewood extraction and charcoal produced are only obtained from exclusively owned forestland, 5 and 6 would be divided by 2.3 ha (Kazungu et al., 2020).

4.1.4. Determinants of forest use strategies

Our analysis highlights some striking differences in the impact of livelihood capitals on a household's forest use strategy choices (Table 6). The livelihood capitals analysed include natural capital, human capital, social capital, financial and physical capital (Scoones, 1998). Other factors included in the analysis are infrastructure and village dummy representing whether a household was located in a landscape with protected or non-protected areas (Table 6). The multinomial logistic (MNL) regression results are analysed with Cluster One (pure subsistence-orientated forest users) as the base category. Thus, positive results imply that the explanatory (independent) variable positively relates to the respective cluster. On the other hand, the negative explanatory effect means that the findings support the base category (Table 6).

Specifically, and in reference to specialised charcoal sellers (Cluster Two), we found that distances to forestlands (private and public forestland), household size and access to roads significantly affected the probability of belonging to specialised charcoal seller's strategy (Table 6). For instance, if distances to private forestland increase, the likelihood of adopting a specialised charcoal seller's strategy declines relative to pure subsistence-orientated forest users (Cluster One), keeping all other factors constant (Table 6). A similar outcome is observed for large household size (human capital) and access to permanent roads (exogenous factors). This finding implies that households that adopted specialised charcoal sellers' strategies stayed closer to forestlands but further away from permanent roads. At the same time, the pure subsistence-orientated were situated further away from forestlands but closer to markets.

Additionally, the probability of being in Cluster Three (forest food and charcoal sellers) instead of Cluster One is significantly influenced by walking distances to public forestlands, off-farm income, and being situated in landscapes with protected forest areas ceteris peribus (Table 6). While the probability of belonging to Cluster One rather than Cluster Three increases with increasing walking distances to private forestlands, age of household head, and access to permanent ceteris paribus (Table 6). These results confirm part (b) of the first hypothesis: *"Livelihood capitals differently influence forest use strategies"*.

These findings imply that access to forest resources and markets in rural areas have an adverse impact on forest use strategies, but these effects cannot be generalized (N. Ali et al., 2020; Babigumira et al., 2014; Nguyen et al., 2015). Although charcoal livelihood strategies are strongly linked to proximity to forestlands (Win et al., 2018), it appears that charcoal activities are mainly illegal (Smith et al., 2017). As such, their production is often done in remote areas further from roads Table 6 (see also Khundi et al. (2011)). This finding implies that the regulatory mechanism for charcoal production in Zambia is limited (Kalaba, 2016; Kalaba, Quinn, & Dougill, 2014).

Furthermore, the findings indicate that assured ownership, such as customary/traditional forest management, is insufficient to address the challenges associated with sustainable forest management in Zambia (Lambini & Nguyen, 2014; Nansikombi et al., 2020). Instead, we advocate for policies and interventions that promote the sustainable production of forest resources, such as reforestation and agroforestry (Reed et al., 2017; Zorrilla-Miras et al., 2018). This will ensure that charcoal producers are integrated into the market system and entice subsistence forest users to engage in cash forest production. Finally, since forest use strategies vary substantially in rural areas and are influenced differently by livelihood capitals, we propose that initiatives also target particular forest user classes (Babulo et al., 2008; Mulenga, Hadunka, & Richardson, 2017; Nguyen et al., 2015).

Table 6. Results of Multinomial Logistic Regression for the determinants of forest-based livelihood strategies (Cluster 1 is a base category) (adapted from Kazungu et al., 2020).

Variables	Coef. Std. Err.	
	Cluster 2 (Specialised charcoal sellers)	**Cluster 3 (Forest food and charcoal sellers)**
Natural capital		
Walking distance from household to public forestland (km)	0.344***(0.100)	0.389***(0.114)
Walking distance from household to private forestland (km)	-0.282***(0.107)	-0.341**(0.153)
Human capital		
Size of Household (number of adult equivalent)	-0.120*(0.072)	0.131(0.093)
Age of head of household (years)	0.007(0.009)	-0.026**(0.013)
Social capital		
Household belongs to the largest ethnic group (1-Lamba; 0-otherwise)	0.347(0.250)	0.248(0.317)
Duration of residence in the village (years)	-0.013(0.010)	0.007(0.012)
Financial capital		
Net income from off-farm (Kwacha)	0.000(0.001)	0.001*(0.001)
Physical capital		
Tropical livestock unit (current stock)	-0.027(0.036)	-0.103(0.058)
Land-size per adult equivalent (ha)	-0.031(0.044)	0.029(0.052)
Infrastructure (exogenous)		
Household had access to road usable throughout the year (yes-1, 0-otherwise)	-0.657**(0.271)	-0.760**(0.369)
Village dummy		
Restriction (village is in restricted arrangement-1, 0-otherwise)[a]	0.176(0.289)	1.159***(0.374)
Constant	-0.184(0.548)	-1.425**(0.717)
Number of observations = 412		
LR chi2 (22) = 99.80		
Prob > chi2 =0.000		
Log likelihood = -371.636		
Pseudo R2=0.118		

*** Significant at 0.01, ** significant at 0.05, *significant at 0.1; standard error in parenthesis. Multicollinearity was checked for by conducting a variance inflation factor (VIF). All the variables had less than 10 VIF. However, variables that showed p>0.5 in Clusters 1 and 2 were removed from the model through manual backward stepwise elimination. [a]Dummy for village fixed effect.

4.2. Deforestation and forest degradation, and their causes along the Miombo forest transition gradient

The main findings from the second publication (Kazungu, Ferrer Velasco, et al., 2021) included: (1) establishing patterns of deforestation across distance categories and along the Miombo forest transition gradient; (2) determining household-level causes of deforestation along the forest transition gradient; and (3) determining the effects of the spatial distribution of agricultural land use on regional deforestation patterns.

4.2.1. Forest cover and deforestation across distance categories and along the Miombo forest transition gradient

The proportion of forest cover substantially varies along the forest transition gradient and across the distance categories representing the areas under the households' influence (Table 7). The North-Western Provinces has about 86% of forest cover, the Copperbelt Province, 68% and the Eastern Province, only 20% of forest cover (Table 7). These results are slightly higher than the remotely sensed data for each province (Hansen et al., 2013). The findings confirm that the study provinces represent the forest transition regions, early forest transition (North-Western Province), mid forest transition (Copperbelt Province), and late forest transition (Eastern Province) (Mather & Needle, 1998; Rudel et al., 2005). These results further imply that integrating household surveys with remotely sensed data to understand smallholder deforestation gives a better understanding of forest cover change in the Miombo areas of Zambia. This finding can be important for land use planning and approaches to preserving the forests.

Regarding deforestation across the study provinces, the Copperbelt Province has the highest rate of deforestation (1.15%), the North-Western, 0.48% and the Eastern Province has the least rate (0.29%) (Table 7). Furthermore, the Copperbelt and the North-Western Provinces have higher deforestation rates at close-distance categories, which decreases across the medium-distance and remote-distance categories (Table 7). In the Eastern Province, we found a revered pattern, with low average deforestation rates across distance categories than the North-Western and the Copperbelt Province (Table 7). This finding supports our second hypothesis, suggesting a decreasing pattern of deforestation across distances from settlements, but only in the early and mid-forest transition regions (Angelsen, 2007; Schielein & Börner, 2018). For the Eastern Province, this finding implies that annual deforestation rates do not often accumulate over time, but deforestation patterns can be cyclical over time (Wolfersberger, Delacote, & Garcia, 2015).

Table 7. The proportion of forest cover and average annual rates of deforestation in distance categories in the study provinces during 2013–2018 (adapted from Kazungu, Ferrer Velasco, et al., 2021).

Distance categories	North-Western Province (Early transition)			Copperbelt Province (Mid transition)			Eastern Province (Late transition)		
	Area (km^2)	**FC[a] (%)**	**Deforestation[b] (%)**	**Area (km^2)**	**FC[a] (%)**	**Deforestation[b] (%)**	**Area (km^2)**	**FC[a] (%)**	**Deforestation[b] (%)**
Close-distance	296.66	82.17	-0.68	548.31	68.63	-1.28	89.67	14.93	-0.21
Medium-distance	494.27	87.88	-0.38	604.00	72.98	-1.04	237.62	21.59	-0.28
Remote-distance	952.39	86.68	-0.39	518.81	61.24	-1.13	427.80	22.04	-0.37
Average	**581.10**	**85.58**	**-0.48**	**557.04**	**67.62**	**-1.15**	**251.70**	**19.52**	**-0.29**

[a] FC (Forest Cover) is calculated as the share of the area with tree cover above 30% for 2000.
[b] Deforestation is the average annual rate of deforestation for the 2013–2018 period, considering the net loss of areas with tree cover above 30%.

4.2.2. Household-level causes of deforestation across the study provinces along the Miombo forest transition gradient

The household-level causes of deforestation analysed in this study are categorised as socio-demographic attributes, land and non-land-based attributes and location factors. These factors differently affect deforestation patterns across the study provinces (Table 8).

The socio-demographic attributes associated with deforestation patterns include household size, ethnicity, education level and residence duration (Table 8 A, B, C). Regarding specific provinces, we found that large household size was associated with a higher probability of high deforestation pattern in the North-Western Province, keeping all other factors constant. In addition, being a member of the largest ethnic group was associated with a lower likelihood of high deforestation patterns in the North-Western Province, keeping all other factors constant (Table 8 A). In the Copperbelt Province, households with better education levels were associated with higher probabilities of high deforestation patterns. At the same time, large household size and residence duration were associated with a reduced likelihood of high deforestation patterns, keeping all other factors constant (Table 8 B).

Conversely, in the Eastern Province, the residence duration was associated with a higher likelihood of high deforestation patterns, keeping all other factors constant (Table 8 C). Although these findings largely align with past studies examining the household causes of deforestation (Babigumira et al., 2014; Mena, Bilsborrow, & McClain, 2006; Twongyirwe et al., 2018), the results demonstrate that the impact of socio-demographic attributes on deforestation patterns vary across regions. This implies that policies to reduce deforestation and forest degradation should often be region-specific.

The land and non-land-based attributes that significantly affected deforestation patterns across the study provinces include land size owned, livestock owned, forest income, crop productivity, capture fish income, off-farm and non-farm incomes (Table 8 A, B, C). Specifically, in the North-Western Province, land and non-land-based attributes mainly were associated with reduced likelihood of high deforestation patterns, keeping all other factors constant (Table 8 A). This suggests that improved economic aspects among households in the North-Western province can positively reduce unsustainable use of forest resources.

Our findings in the Copperbelt Province show that land and non-land-based attributes affect deforestation patterns differently (Table 8 B). Larger livestock units, as well as increases in forest income and crop productivity, were associated with an increased likelihood of high deforestation patterns, holding all other factors constant (Table 8 B). In contrast, increased income from capture fish and non-farm activities was associated with a reduced likelihood of high deforestation patterns, keeping all other factors constant (Table 8 B).

In the Eastern Province, we found that cereals crop and vegetable productivity were associated with an increased likelihood of high deforestation patterns, holding all other factors constant (Table 8 C). Overall, we note that increases in legumes productivity and non-farm incomes were consistently associated with reduced likelihood of high deforestation patterns across the study provinces, but these variables were not always significant (Table 8 A, B, C). Despite variations across regions, our findings show that differentiation of livelihood portfolios remains an important factor in changing deforestation patterns in Zambia's Miombo landscapes.

The location attributes that were significantly associated with deforestation patterns in the study provinces include access to permanent roads, distances to the markets (roads and centre of the village), and distances to land use patches (distance categories) (Table 8 A, B, C). These factors had different impacts on deforestation across the provinces. In the North-Western and the Eastern Province, access to permanent roads was significantly associated with high deforestation patterns, holding all other factors constant (Table 8 A and C). And increases in the distances to the markets reduced the likelihood of high deforestation patterns, holding all other factors constant. Conversely, in the Copperbelt Province, the market variables were largely not significantly associated with high deforestation, except for distance to the centre (Table 8 B). Households located in landscapes with partly forest reserves were associated with reduced likelihood of high deforestation holding all other factors constant. Lastly, land distribution across patches of land differently affected deforestation across provinces, holding all other factors constant (Table 8 A, B and C). This finding indicates that distances to patches of land use and markets can determine variations in agricultural land use and deforestation along the Miombo forest transition gradient.

Overall, our findings confirm hypothesis two, part (a), which states that *“Household-level causes of deforestation vary regionally across the forest landscapes”*. These findings provide vital information for policymakers that seek to understand the underlying causes of deforestation to reconcile conservation policies with rural development agendas. It also provides relevant information for rural land use planning. The following subsection examines the impact of distances to patches of land use (i.e., the spatial distribution of agricultural land use) and their impacts on deforestation patterns.

Table 8. Generalised ordered logit model results of household-level attributes and agricultural land use on regional deforestation patterns in the study area (adapted from Kazungu, Ferrer Velasco, et al., 2021).

A. **North-Western Province**

Variables	Marginal effects		
	Deforestation levels		
	Low	Medium	High
Socio-demographic attributes			
Age of household head, years	0.0000827 (0.0171)	-0.0000127 (0.00262)	-0.00007 (0.0145)
Male-headed household, 1=Yes; 0=No	0.0183 (0.0411)	-0.00269 (0.00584)	-0.0156 (0.0353)
Head of household attained above primary education, 1=Yes; 0=No	-0.0194 (0.0373)	0.00278 (0.00506)	0.0166 (0.0323)
Household size, Number of members	-0.0361** (0.016)	0.00553* (0.00305)	0.0306** (0.0134)
Duration of residence in the village, years	0.0262 (0.0215)	-0.00401 (0.00358)	-0.0222 (0.0181)
Household head belongs to the largest group, Lunda=1; Others =0	0.0929** (0.0381)	-0.0142* (0.00824)	-0.0787** (0.0309)
Land-based attributes			
Total size of patches land owned, ha	0.0418* (0.0228)	-0.0064 (0.00413)	-0.0354* (0.0192)
Livestock, tropical livestock unit (TLU)	0.0463* (0.0273)	-0.0071 (0.00463)	-0.0392* (0.0232)
Forest products (unprocessed), ZMW	0.0365* (0.0218)	-0.00559 (0.00371)	-0.0309* (0.0185)
Charcoal production, ZMW	0.0489 (0.0688)	-0.00749 (0.011)	-0.0414 (0.0581)
Capture fish, ZMW	0.0420*** (0.0114)	-0.00644*** (0.00245)	-0.0356*** (0.0098)
Off-farm income, ZMW	0.00848 (0.0143)	-0.0013 (0.00223)	-0.00718 (0.0121)
Cereals crop production, ZMW/ha/yr[a]	0.0284** (0.0137)	-0.0194*** (0.00538)	-0.00903 (0.012)
Vegetable production, ZMW/ha/yr	0.00199 (0.0199)	0.00381 (0.01)	-0.0058 (0.0198)
Legumes production, ZMW/ha/yr	0.0203 (0.0134)	-0.00923* (0.0049)	-0.0111 (0.0112)
Non-land-based attributes			

Non-farm income, ZMW	0.0452*** (0.016)	-0.00692** (0.00299)	-0.0382*** (0.0138)
Location attributes			
Household had access to permanent road, 1=Yes; 0=No	-0.102** (0.0471)	0.0212* (0.0124)	0.0811** (0.0356)
Household's distance to main road, walking time (minutes)	0.0913*** (0.012)	-0.0140*** (0.00458)	-0.0773*** (0.01)
Household's distance to the centre of the village, walking time (minutes)	-0.0349 (0.0294)	0.00535 (0.00487)	0.0296 (0.0247)
Landscape has forest reserve, 1= Yes; 0=No	0.487*** (0.0435)	0.0364 (0.0258)	-0.523*** (0.047)
Land-use patch in medium-distance (close is base outcome)	0.134*** (0.0404)	-0.0252 (0.0183)	-0.109*** (0.0299)
Land-use patch in remote-distance (close is base outcome)	-0.198*** (0.0393)	-0.0754*** (0.0279)	0.273*** (0.0497)
Log-likelihood	-257.05		
Pseudo R^2	0.37		
N	374		

B. Copperbelt Province

Variables	Marginal effects — Deforestation levels: Low	Medium	High
Socio-demographic attributes			
Age of household head, years	-0.0335 (0.0227)	0.00737 (0.00535)	0.0261 (0.0177)
Male-headed household, 1=Yes; 0=No	-0.0702 (0.0662)	0.0193 (0.0219)	0.051 (0.0447)
Head of household attained above primary education, 1=Yes; 0=No	-0.0872* (0.0449)	0.0145** (0.00713)	0.0727* (0.04)
Household size, Number of members	0.0424** (0.0205)	-0.00933* (0.00502)	-0.0330** (0.0161)
Duration of residence in the village, years	0.0544** (0.0239)	-0.0120** (0.00594)	-0.0424** (0.0189)
Household head belongs to the largest group, Lamba=1; Others =0	-0.0457 (0.0417)	0.0101 (0.00954)	0.0356 (0.0326)
Land-based attributes			
Total size of patches of land owned, ha	-0.00649 (0.0148)	0.00143 (0.00328)	0.00506 (0.0115)
Livestock, tropical livestock unit (TLU)	-0.0324* (0.018)	0.00714* (0.00434)	0.0253* (0.0141)
Forest products (unprocessed), ZMW	-0.107*** (0.0216)	0.0236*** (0.0081)	0.0836*** (0.0163)
Charcoal production, ZMW	-0.0122 (0.0152)	0.00268 (0.00338)	0.00949 (0.0119)
Capture fish, ZMW	0.0576* (0.0307)	-0.0127* (0.00715)	-0.0449* (0.0243)
Off-farm income, ZMW	-0.00662 (0.0278)	0.00146 (0.00616)	0.00516 (0.0217)
Cereals crop production, ZMW/ha/yr[a]	-0.0759** (0.0349)	0.00358 (0.0109)	0.0723** (0.0283)
Vegetable production, ZMW/ha/yr	0.00673 (0.0187)	-0.0093 (0.0066)	0.00258 (0.0139)
Legumes production, ZMW/ha/yr	0.0471 (0.0354)	-0.0117 (0.0122)	-0.0354 (0.0264)
Non-land-based attributes			
Non-farm income, ZMW	0.0382* (0.0201)	-0.00841* (0.00478)	-0.0297* (0.0158)
Location attributes			
Household had access to permanent road, 1=Yes; 0=No	0.0731 (0.0511)	-0.0177 (0.0139)	-0.0554 (0.0378)

Household's distance to main road, walking time (minutes)	0.048 (0.0415)	-0.0106 (0.00958)	-0.0374 (0.0324)
Household's distance to the centre of the village, walking time (minutes)	0.0392* (0.0225)	-0.00864 (0.00527)	-0.0306* (0.0177)
Landscape has forest reserve, 1= Yes; 0=No	0.0296 (0.0495)	-0.00648 (0.0107)	-0.0231 (0.0389)
Land-use patch in medium-distance (close is base outcome)	0.224*** (0.0431)	-0.0283 (0.0182)	-0.196*** (0.0368)
Land-use patch in remote-distance (close is base outcome)	0.054 (0.051)	0.0123 (0.0155)	-0.0663 (0.0513)
Log-likelihood	-364.48		
Pseudo R2	0.15		
N	394		

C. Eastern Province

Variables	Marginal effects		
	Deforestation levels		
	Low	Medium	High
Socio-demographic attributes			
Age of household head, years	-0.00663 (0.0187)	0.00128 (0.00358)	0.00536 (0.0151)
Male-headed household, 1=Yes; 0=No	0.0244 (0.0392)	-0.00467 (0.00742)	-0.0198 (0.0318)
Head of household attained above primary education, 1=Yes; 0=No	0.0406 (0.0439)	-0.00831 (0.00948)	-0.0323 (0.0346)
Household size, Number of members	-0.00514 (0.0177)	0.000988 (0.00342)	0.00415 (0.0143)
Duration of residence in the village, years	-0.0427** (0.0175)	0.00822** (0.00391)	0.0345** (0.0139)
Household head belongs to the largest group, Nsenga=1; Others =0	-0.034 (0.0967)	0.00654 (0.0186)	0.0274 (0.0781)
Land-based attributes			
Total size of patches of land owned, ha	-0.0593 (0.061)	0.0114 (0.0117)	0.0479 (0.0495)
Livestock, tropical livestock unit (TLU)	0.0322* (0.0195)	-0.0062 (0.00383)	-0.026 (0.0159)
Forest products (unprocessed), ZMW	-0.00696 (0.0302)	0.00134 (0.00588)	0.00562 (0.0243)
Charcoal production, ZMW	-0.138 (0.116)	0.0266 (0.0218)	0.112 (0.0948)
Capture fish, ZMW	-0.0153 (0.036)	0.00294 (0.00691)	0.0123 (0.0291)
Off-farm income, ZMW	-0.00288 (0.0158)	0.000555 (0.00306)	0.00233 (0.0128)
Cereals crop production, ZMW/ha/yr[a]	-0.0438** (0.0187)	0.00152 (0.00535)	0.0423*** (0.016)
Vegetable production, ZMW/ha/yr	-0.0571 (0.0396)	0.0207*** (0.00798)	0.0364 (0.0367)
Legumes production, ZMW/ha/yr	0.0117 (0.0313)	-0.0106 (0.0107)	-0.00104 (0.0244)
Non-land-based attributes			
Non-farm income, ZMW	0.0156 (0.0207)	-0.003 (0.004)	-0.0126 (0.0167)
Location attributes			
Household had access to permanent road, 1=Yes; 0=No	-0.0932*** (0.0327)	0.0175** (0.00681)	0.0757*** (0.0266)
Household's distance to main road, walking time (minutes)	0.0761 (0.0915)	-0.0146 (0.0172)	-0.0614 (0.0746)

Household's distance to the centre of the village, walking time (minutes)	0.0741*** (0.0206)	-0.0142*** (0.00511)	-0.0598*** (0.0163)
Landscape has forest reserve, 1= Yes; 0=No	0.553*** (0.0378)	-0.0980*** (0.0336)	-0.455*** (0.0351)
Land-use patch in medium-distance (close is base outcome)	-0.301*** (0.047)	0.0721** (0.0299)	0.229*** (0.0265)
Land-use patch in remote-distance (close is base outcome)	-0.355*** (0.0569)	0.0672** (0.03)	0.288*** (0.0435)
Log-likelihood	-242.68		
Pseudo R2	.37		
N	355		

*** p<0.01, ** p<0.05, * p<0.1. Standard errors in parentheses

Footnotes:
dy/dx for factor levels is the discrete change from the base level.
Outliers and multilinearity checks were conducted before performing econometric estimations.
[a]Crop income effects on deforestation are further analysed across distances categories.

4.2.3. The effects of the spatial distribution of agricultural land use on regional deforestation patterns

This subsection shows the implications of the spatial distribution of agricultural land use on deforestation patterns along the forest transition gradient. In the North-Western Province, increased cereals crop productivity (subsistence crop) was associated with a higher likelihood of high deforestation patterns at close-distance and remote-distance categories, keeping all other factors constant (Table 9 A). On the other hand, increased vegetable and legumes productivity (commercial crops) was associated with a reduced likelihood of high deforestation patterns at close-distance and medium-distance categories but were not statistically significant (Table 9 A).

In the Copperbelt Province, crop productivity has significant and contrasting effects on deforestation patterns (Table 9 B). Notably, increased cereals crop productivity was associated with a higher likelihood of high deforestation patterns at a close-distance category, keeping all other factors constant. In contrast, vegetable productivity was associated with a reduced likelihood of high deforestation in the medium-distance category, holding all other factors constant. This finding correlates with earlier results in Table 7, showing high deforestation at close-distance categories in the Copperbelt Province.

Regarding the Eastern Province, cereal crop productivity increases were associated with a higher likelihood of high deforestation at the medium-distance category, keeping all other factors constant. On the other hand, increased vegetable productivity was associated with an increased probability of high deforestation patterns at the close-distance category, holding all other factors constant (Table 9 C).

This finding partly confirms part (b) of hypothesis two suggesting that *agricultural land use can be associated with distances to settlements and deforestation along the forest transition gradient* (Angelsen, 2007). However, the results do not support the views that suggest *higher deforestation patterns closer to settlements (processing centres) can be associated with high return crops (commercial crops)* (see von Thünen, 1826). These findings have several implications. First, the results imply that crop productivity does not consistently relate to distance categories and along the forest transition. Second, the results mean that the patterns of deforestation in the Miombo woodlands are mainly subsistence driven (D. Phiri et al., 2019b) and thus, independent from return-related deforestation patterns. These findings partly suggest that in some provinces of Zambia, high crop returns can substitute for forest product extraction (Mulenga et al., 2017). And these results indicate that the von Thünen (1826) theory does not apply in agrarian economies with limited markets. We explain the impact of these economic trade-offs in livelihood strategies on household decisions to participate in programmes aimed at preserving forests while improving livelihoods in the following subsection (forest support programmes).

Table 9. Generalised ordered logit estimates of the spatial distribution of agricultural land-use on regional deforestation (adapted from Kazungu, Ferrer Velasco, et al., 2021)[a].

A. North-Western Province

Variables	Marginal effects		
	Deforestation levels		
	Low	**Medium**	**High**
Crop productivity at varying distance categories			
Cereals crop productivity, ZMW/ha/yr			
Close-distance	-0.0272	0.0691***	-0.0290
	(0.0244)	(0.0199)	(0.0193)
Medium-distance	0.00419	-0.0233***	-0.0312*
	(0.00411)	(0.00695)	(0.0182)
Remote-distance	0.0230	-0.0458***	0.0602*
	(0.0210)	(0.0137)	(0.0352)
Vegetable productivity, ZMW/ha/yr			
Close-distance	0.0800	-0.0332	-0.000103
	(0.0583)	(0.0206)	(0.0371)
Medium-distance	-0.0124	0.0112	-0.000111
	(0.0119)	(0.00706)	(0.0399)
Remote-distance	-0.0677	0.0220	0.000214
	(0.0484)	(0.0137)	(0.0770)
Legumes crop productivity, ZMW/ha/yr			
Close-distance	0.0229	0.0282	-0.0125
	(0.0241)	(0.0193)	(0.0156)
Medium distance	-0.00353	-0.00950	-0.0135
	(0.00397)	(0.00645)	(0.0148)
Remote-distance	-0.0193	-0.0187	0.0260
	(0.0207)	(0.0130)	(0.0298)
Observations	374	374	374

B. Copperbelt Province

Variables	Marginal effects		
	Deforestation levels		
	Low	Medium	High
Crops productivity at varying distance categories			
Cereals crop productivity, ZMW/ha/yr			
Close-distance	-0.157*** (0.0592)	-0.0178 (0.0180)	0.175*** (0.0615)
Medium-distance	-0.0430 (0.0443)	0.0186 (0.0193)	0.0244 (0.0253)
Remote-distance	-0.0310 (0.0908)	0.00261 (0.00853)	0.0284 (0.0833)
Vegetable productivity, ZMW/ha/yr			
Close-distance	-0.0234 (0.0237)	-0.00266 (0.00365)	0.0261 (0.0261)
Medium-distance	0.0517* (0.0305)	-0.0224* (0.0135)	-0.0293* (0.0176)
Remote-distance	-0.0537 (0.0351)	0.00452 (0.00792)	0.0491 (0.0318)
Legumes crop productivity, ZMW/ha/yr			
Close-distance	0.0447 (0.0460)	0.00508 (0.00754)	-0.0497 (0.0514)
Medium-distance	0.0667 (0.0596)	-0.0289 (0.0260)	-0.0378 (0.0341)
Remote-distance	0.00479 (0.0551)	-0.000404 (0.00463)	-0.00439 (0.0505)
Observations	394	394	394

C. Eastern Province

Variables	Marginal effects		
	Deforestation levels		
	Low	Medium	High
Crops productivity at varying distance categories			
Cereals crop productivity, ZMW/ha/yr			
Close-distance	0.00328 (0.0300)	-0.00181 (0.0165)	-0.00148 (0.0135)
Medium-distance	-0.0679*** (0.0231)	0.00443** (0.00210)	0.0635*** (0.0222)
Remote-distance	-0.0312 (0.0575)	0.00164 (0.00284)	0.0296 (0.0551)
Vegetable productivity, ZMW/ha/yr			
Close-distance	-0.112** (0.0467)	0.0614** (0.0294)	0.0502** (0.0229)
Medium-distance	-0.0215 (0.0596)	0.00140 (0.00359)	0.0201 (0.0560)
Remote-distance	-0.0915 (0.0777)	0.00480 (0.00599)	0.0867 (0.0743)
Legumes crop productivity, ZMW/ha/yr			
Close-distance	0.0960 (0.0635)	-0.0528 (0.0347)	-0.0432 (0.0319)
Medium-distance	-0.00223 (0.0322)	0.000146 (0.00211)	0.00209 (0.0301)
Remote-distance	-0.0668 (0.105)	0.00350 (0.00713)	0.0633 (0.0985)
Observations	355	355	355

*** p<0.01, ** p<0.05, * p<0.1. Standard errors in parentheses

Footnotes:
[a] Table 9 is a continuation of the generalised ordered regression model; here, we estimate interactions between income and distance categories (i.e., how incomes per crop type vary across distance categories).

4.3. Determinants of participation in forest support programmes in the Miombo forest landscapes

The third paper (Kazungu, Zhunusova, et al., 2021) seeks to evaluate various hypotheses regarding households participation in Forest Support (FS) programmes in the Miombo landscapes of Zambia. Household-level factors are classified into socio-demographic attributes and economic and access factors.

4.3.1. Household-level factors affecting participation in forest support programmes

Previous research has shown that rural households in forested areas engage in various activities for a living but rely primarily on forest use and agricultural production (Kazungu, Ferrer Velasco, et al., 2021; Kazungu et al., 2020). This suggests that the economic benefits associated with different livelihood activities seem to influence households decisions regarding a particular activity, which in turn affects sustainable outcomes (see also Bush, Hanley, and Rondeau (2011)). This subsection shows how the economic costs and benefits associated with household-level attributes such as income from various sources of livelihoods influence households' decisions to participate in forest support programmes. We found that household education levels, landholding size, income shares from various sources, distances to markets, forestlands, and forest management regimes were all significantly correlated with participation in forest support programmes (Table 10).

In particular, we note that households with better education levels had lesser incentives (7.4 percentage points) to participate in FS programmes, keeping all other factors constant (Table 10). This finding suggests that households with better education levels depend less on forest resources and have no interest in forest issues. The result means that in order to increase participation in FS programmes, interventions should target less educated households because this can improve attitude towards the environment and enhance household socio-economic status (Agrawal & Gupta, 2005; Kauneckis & York, 2009).

Furthermore, we found that improvements in households economic attributes reduced the likelihood of participation in FS programmes. For instance, households with large landholdings were more likely not to participate in forest support programmes than their counterparts with small landholdings; the percentage point is 0.7, keeping all other factors constant (Table 10). Additionally, higher shares of non-forest-based income (crop, fish, and non-farm income) have a more significant and negative effect (0.4 – 5.8 percentage points) on participation than higher shares of forest income (0.3 – 0.4 percentage points), keeping all other factors constant (Table 10).

Access to forests and markets were significant and negative (Table 10). For instance, an increase in the household's walking time to the main roads and distances to the forestland reduced the likelihood of participation in FS programmes by 0.1 and 6.8 percentage points, respectively, keeping all other factors constant (Table 10). This result means that further distances to forests much more affect participation than distances to the markets (Babigumira et al., 2014; Charles Jumbe & Angelsen, 2007). Thus, this study suggests that in order to increase participation in FS programmes, interventions should often target households situated closer to forests. Furthermore, this research also found that households located in protected areas are highly likely to participate in FS programmes than their counterparts situated in landscapes without protected areas; the percentage point is 13.6, keeping all other factors constant (Table 10). This finding appears to suggest that in the Miombo regions of Zambia, rural households located closer or within the protected areas are aware of the benefits and potential consequences of forest programmes on their livelihoods, as such households are often motivated to participate in FS programmes (GRZ, 1995, 2015).

Overall, these results do not wholly confirm the third hypothesis, *“Household-level factors affect participation in forest support programmes in different ways”*. The results demonstrate that household-level factors were mainly directional, and improvements in household-level attributes were linked to a lower probability of participating in forest support programmes. The implication of these findings are as follows: first, the result implies that increased dependence on forest resources can jeopardise participation in FS programmes because households are likely to perceive programmes as restrictive. Second, the finding means that non-forest-based activities have higher opportunity costs than forest-based livelihoods (Badal, Kumar, & Bisaria, 2006). As such, it becomes difficult for households that have invested in non-forest-based livelihoods to switch to forest use, thus creating lesser interests in forest programmes (Charles Jumbe & Angelsen, 2007; M. Phiri, Chirwa, Watts, & Syampungani, 2012).

Table 10. Logistic regression results of determinants of participation in forest support programmes (adapted from Kazungu, Zhunusova, et al., 2021).

Variables	Coefficients	Marginal effect (dy/dx)
Socio-demographic factors		
Age of head of household (Years)	0.006 (0.005)	0.001 (0.001)
Male-headed household (Yes=1; No=0)	0.236 (0.190)	0.052 (0.041)
Household head attained above primary education (Yes=1; No=0)	-0.339** (0.169)	-0.074 (0.037)
Household size (AEU)	0.035 (0.037)	0.008 (0.008)
Economic factors		
Land holding size (ha)	-0.031* (0.016)	-0.007 (0.003)
Livestock income (%)	-5.80×10^{-5} (4.97×10^{-5})	-1.27×10^{-5} (1.09×10^{-5})
Subsistence forest income (unprocessed forest products) (%)	-0.018*** (0.005)	-0.004 (0.001)
Charcoal income (processed forest products) (%)	-0.012*** (0.004)	-0.003 (0.001)
Cash crop income (%)	-0.023*** (0.005)	-0.005 (0.001)
Capture fish income (%)	-0.264*** (0.065)	-0.058 (0.014)
Non-farm income (%)	-0.019*** (0.007)	-0.004 (0.001)
Access factors		
Walking distance from household to main road (minutes)	-0.004*** (0.001)	-0.001 (0.000)
Walking distance from household to public forestland (km)	-0.310*** (0.051)	-0.068 (0.011)
Household in landscapes with protected forest area (Yes=1; No=0)	0.620*** (0.141)	0.136 (0.031)
Constant	0.878** (0.435)	
LR X^2 (14)	197.56	
Prob> X^2	0.000	
McFadden's R^2	0.13	
Log-likelihood	-639.88	
Observations	1,123	1,123

*** p<0.01, ** p<0.05, * p<0.1. Standard errors in parentheses

5. Synthesis: Sustainable development, constraints and potential pathways

Is the current land use in the tropical and subtropical dry forest areas sustainable? If so, is it possible to minimise forest resource depletion while simultaneously improving household well-being? Addressing these concerns helps us to understand better the diverse and multiple linkages between household and contextual factors, livelihood strategies, deforestation and forest degradation, and their implications on the achievement (or not) of sustainable outcomes (improved livelihoods and reduced deforestation). We discuss the previous theories on forest use, livelihoods and poverty, and land use change in the context of sustainable development. Thus, the section is organised as follows: (1) sustainable livelihood framework in rural households' analysis; (2) the role of forest products in forest use strategies; (3) the importance of livelihood capitals in forest use strategies; (4) livelihood activities and land use change along the forest transition; and (5) household-level attributes associated with participation in forest support programmes in the Miombo areas of Zambia.

5.1. Sustainable Livelihood (SL) framework and rural households' analysis

The SL approach has long been used to describe rural development processes (Ashley & Carney, 1999; Chambers & Conway, 1992). It implies that rural households have a diverse range of livelihood capitals that they can use to achieve specific livelihood outcomes (Scoones, 1998). A livelihood is considered sustainable if it can cope with shocks and maintain its capabilities, capitals, and natural resource base over time (Ashley & Carney, 1999). Despite the diversity of rural livelihood activities (Ellis, 2000), they often do not provide adequate subsistence and cash income to protect households from material and financial hardship (Sultana, Hossain, & Islam, 2015; Vedeld et al., 2007). This is because rural livelihood activities are frequently influenced by different household-level attributes and context-specific factors (Adhikari et al., 2004; A. Ali & Rahut, 2018; Nguyen et al., 2015) that can vary across landscapes and regions (Angelsen et al., 2014; Babigumira et al., 2014). Although previous studies have recognized the importance of household attributes and contextual factors in rural development outcomes, many studies using the SL approach have not thoroughly explained how the diverse interactions of household-level attributes and contextual factors, livelihood capitals, and land use change can affect the achievement (or not) of sustainable outcomes. We narrowly define sustainable outcomes to imply improved livelihoods and reduced deforestation. Thus, the purpose of this study was to better understand these “household-level” interconnections and their implications for livelihoods. These interconnections are discussed further in the following subsections.

5.2. The role of forest products in forest use strategies

Studies on forests and livelihoods have recorded that forest resources are essential sources of household income in many developing countries (N. Ali et al., 2020; Babulo et al., 2008; Kalaba et al., 2013a; Nguyen et al., 2015; Soltani et al., 2012). Furthermore, in the tropical areas, it is recorded that the contribution of forest resources to total household income is as much as for crops (Angelsen et al., 2014). This suggests that forests are primary sources of livelihood for rural households and that improvements in extraction can help enhance the household economic status, thereby reducing rural poverty (Sunderlin et al., 2005; Vedeld et al., 2007). In addition, forest resources contribute to household subsistence income and provide substantial cash income to some households (Jones et al., 2016; Njana et al., 2013; Smith et al., 2017). As such, there is a potential for higher incomes if access to markets and forestland are improved (Adhikari et al., 2004; B. Belcher, Achdiawan, & Dewi, 2015; B. M. Belcher, 2005).

Conversely, it is recorded elsewhere that rural households derive more income from non-forest environments than forests (Pouliot & Treue, 2013; Pouliot, Treue, Obiri, & Ouedraogo, 2012). As such, to improve the well-being of rural households, there is a need to convert forests to non-forest land types since non-forest environments generate more benefits than forests (Pouliot et al., 2012). However, there is a consensus among most studies that forest resources are an essential source of income for most households inhabiting the forest landscapes and that poor households are disproportionately dependent on forests, particularly woodfuel (Angelsen et al., 2014; Pouliot & Treue, 2013; Vedeld et al., 2007). This high reliance is frequently cited as a reason to enhance investments in sustainable forest management in order to increase household income and alleviate poverty.

Despite a plethora of literature on forests and livelihoods (Adhikari et al., 2004; A. Ali & Rahut, 2018; Kamanga et al., 2009; Sardeshpande & Shackleton, 2020), previous research has not explained the roles of forest products in forest use strategies. Understanding the importance of forest products in forest use strategies helps develop targeted policy interventions aimed at specific forest users. Therefore, this research distinguishes the role of forest products in forest use strategies, assesses context-specific extraction and factors related to forest use, focusing on livelihood capitals (Scoones, 1998). We found that forest products differently contributed to household forest use strategies (Kazungu et al., 2020). The forest use strategy choices that households adopted were pure subsistence-orientated forest users, specialised charcoal sellers and forest food and charcoal sellers' strategy. Charcoal livelihood strategies (i.e., specialised charcoal sellers and forest food and charcoal sellers) were the most lucrative, providing households with higher cash income. Compared to other livelihood activities, charcoal production alone generated more household income than income generated from agriculture activities combined (i.e., crops, livestock, and capture fish) (Kazungu et al., 2020).

However, charcoal production was spatially contextual; households in protected areas produced more charcoal and earned higher incomes than their counterparts in non-protected forest areas (Kazungu et al., 2020). This means protected areas still have productive forests bearing the risk of being accessed and used illegally. These results imply that forest resources can help increase household income and thus well-being, but only if they are available and harvested sustainably in a long-term perspective. Furthermore, forest use strategies were affected differently by household capitals, indicating that improvements in livelihood resources cannot be universally beneficial to all households (this is explained in detail in the following subsection).

5.3. The importance of livelihood capitals in forest use strategies

According to previous studies, households often follow various livelihood strategies based on the livelihood capitals they possess (Babulo et al., 2008; Nguyen et al., 2015; Soltani et al., 2012). For example, distances to forests (natural capital), household size (human capital), socio-cultural group (social capital), and road types are all recorded to have a significant impact on households that follow subsistence strategies, which primarily consist of the use of unprocessed forest products (Nguyen et al., 2015). In contrast, improvements in landholding size (physical capital) and access to credit (financial capital) have been observed to influence cash orientated or mixed livelihood strategies (i.e., use of unprocessed and processed forest products and agriculture) (Soltani et al., 2012). This is because access to land and financial capital can provide cash for buying inputs and thereby help diversify households' sources of income.

Despite previous research attempting to understand factors associated with variations in households’ livelihood strategies, little is known about household capitals (livelihood resources) that influence variations in forest use choices in the Miombo areas of Zambia. This research observed that households adopted distinct forest use strategies based on different combinations of livelihood resources at their disposal (Kazungu et al., 2020). Specifically, we found that longer distances to forestlands (natural capital), larger household size (human capital) and access to permanent roads (exogenous factor), influenced the adoption of the subsistence forest use strategy (Kazungu et al., 2020). Charcoal forest use strategies (specialised charcoal sellers and forest food and charcoal sellers' strategy) were positively associated with distances to public forestlands (natural capital), off-farm income and location of the landscape (i.e., higher extraction in protected areas). Access to permanent roads adversely affected charcoal production. This result indicates that charcoal production is actively done in public forestlands that are mainly located in remote areas.

As a result, we suggest that policy interventions in the field should adopt techniques that promote sustainable production, such as reforestation and agroforestry (Reed et al., 2017). This can ensure that charcoal production is integrated into the market system, attracting subsistence forest users to participate in forest production for cash. The results also imply that assured land ownership, such as customary/traditional forest management alone, cannot solve the challenges associated with sustainable forest management in Zambia (see also Lambin & Nguyen., 2014). Lastly, since forest product extraction was context-specific, policies and interventions should be specific too, targeting specific user groups across the different provinces and along the forest transition gradient (further explained below).

5.4. Livelihood activities and land use change along the forest transition

Forest resource use declines through different stages of development, which implies that there are increased opportunities in agricultural land use, but also suggests decreases in the type of forest products along the forest transition (Angelsen, 2007; Barbier et al., 2010). The forest transition describes forest cover changes over a long period (Mather, 1992). It explains how economic development processes such as road expansion and urban growth can affect forest cover and agricultural land use (Angelsen, 2007; Rudel et al., 2005). This suggests that forest resources tend to be abundant prior to economic development, then decline and later re-emerge at the late stage (Mather & Needle, 1998). Further, this view appears to suggest that higher incomes can be associated with increased pressures on forests (see also DeFries, Rudel, Uriarte, and Hansen (2010) S. J. Ryan et al. (2017)). However, elsewhere studies have indicated that pressures on forest resources are a result of multiple factors interacting together and that these factors are different across landscapes and forest transition regions (Babigumira et al., 2014; De Sherbinin et al., 2008; Ferrer Velasco, Köthke, Lippe, & Günter, 2020; Twongyirwe et al., 2018). Despite variations in rural livelihood activities and land use along the forest transition, forest resources extraction and agricultural land use remain the major causes of deforestation in the tropical dry forest areas (Geist & Lambin, 2002; Hosonuma et al., 2012; Kissinger et al., 2012).

In the Miombo areas of Zambia, this research has shown that household deforestation rates vary across distances from population centres (homesteads) (von Thünen, 1826) and along the forest transition (Kazungu, Ferrer Velasco, et al., 2021). A decreasing pattern of deforestation across distances from homesteads is observed in the early and mid-forest transition regions, while the late transition regions showed a reversed pattern. The causes of deforestation were regionally specific but mainly attributed to dependencies on subsistence activities. For example, forest resource extraction was strongly linked to high deforestation in the Copperbelt Province. In contrast, improved economic attributes were strongly linked to a lower likelihood of high deforestation in the North-Western and Eastern Provinces.

Furthermore, non-farm incomes were related to reduced deforestation patterns but not always consistent across distance categories or along the forest transition (provinces). First, this finding suggests that the economic impact of distances to populations areas complement the forest transition effects (Kazungu, Ferrer Velasco, et al., 2021). Second, the results indicate that improved households' economic status does not always translate into lower forest resource demand (Kazungu et al., 2020). Instead, the economic costs and benefits associated with forest-related issues appear to differently influence household decisions about forest use (Fisher, 2012; Larson, 1994) (this is further discussed in the following subsection).

5.5. Impact of household-level factors on participation in forest support programmes

Rural households form about half of the population (World Bank, 2021). These households mainly depend on forest resources and agricultural production for their livelihoods (Angelsen et al., 2014; Vedeld et al., 2007). Moreover, forestlands are the sources of land for agricultural expansion and provide ecosystem services that sustain agricultural production (Gibbs et al., 2010; Miles et al., 2006). Thus, rural households are important actors in forests and natural resources management (Call et al., 2017). It, therefore, becomes important to understand household-level attributes that affect participation in forest programmes as an important step for interventions seeking to achieve sustainable rural development (Agrawal & Gupta, 2005; Fisher, 2012).

Previous research suggests that various factors influence households' participation in programmes seeking to protect forest resources while improving the household's well-being (Baynes et al., 2015). And these factors can include the age of the head of household, gender, household size, education and ethnicity, incomes (i.e., crops, forests and non-farm incomes), access to land and markets. While household-level factors are important, their impact on participation in forest support programmes varies across studies (Coulibaly-Lingani et al., 2011; Dolisca et al., 2006; Charles Jumbe & Angelsen, 2007; Lise, 2000). Although there are no consistent findings across studies regarding the effect of household-level features on participation, the majority of studies agree that changes in certain household attributes, such as education and income, will improve attitudes toward environmental issues, increase income, and thus improve household well-being (Nakakaawa, Moll, Vedeld, Sjaastad, & Cavanagh, 2015; Sunderlin et al., 2005). This, in turn, influences participation in forest programmes leading to reduced pressures on forest resources (Coleman & Mwangi, 2013; Charles Jumbe & Angelsen, 2007; Neitzel et al., 2014).

This research sought to test the impact of household-level attributes, including better education and higher incomes, on the household's decision to participate in forest support programmes in the Miombo areas of Zambia. We note that households with better education levels had lesser incentives to participate in forest support programmes (Kazungu, Zhunusova, et al., 2021). Moreover, a higher share of household incomes (forests, crops and non-farm-based incomes) reduced the likelihood of participation in forest support programmes. Other factors that were significant and negatively associated with participation in forest support programmes include landholding size, distances to markets, forestlands and location of households (Kazungu, Zhunusova, et al., 2021). These findings suggest that the opportunity costs associated with education and rural income investment are higher in rural areas (see also Bush et al. (2011); Fisher (2012)). As such, households with better education and higher income have lesser incentives to participate in forest support programmes (Badal et al., 2006; Nyirenda, Myburgh, Reilly, Phiri, & Chabwela, 2013). Therefore, this finding implies that improvements in the household's social and economic status in the forested landscapes do not automatically lead to environmental attitude change and interests in forest-related issues. However, to attract households to participate in forest programmes, intervention needs to mainly target poor households with limited incomes, lower education, and little access to markets. The programmes provide incentives to improve household well-being while simultaneously aiming to preserve forest resources.

6. Conclusions

Based on the findings in this research, it was possible to draw the following conclusions:

The sustainable livelihood (SL) framework is an important tool for visualising the complex and interconnected links between household attributes, contextual factors, livelihoods and land use change at the household scale. The SL approach suggests that rural households possess different livelihood capitals that they deploy to follow specific livelihood strategies, leading to the achievement of sustainable outcomes (i.e., improved livelihoods and reduced deforestation) (Scoones, 1998). Although the SL framework has been widely applied to understand the processes of rural development in many developing countries, previous research did not show how household-level attributes, contextual factors and livelihood resources (capitals) can be associated with land use change (deforestation and forest degradation), and their implications for livelihoods. In most developing countries, rural livelihoods are mainly derived from land use (i.e., forest extraction and agricultural production) (Angelsen et al., 2014). As a result, rural households more often increase their extraction of forest resources and expand their land in order to improve their income and well-being; however, this can result in deforestation and forest degradation. This demonstrates that household-level attributes, contextual factors and land use change are interconnected and differently affect livelihoods. A better understanding of these dynamics and interactions at the household level is vital for research and policy legislation that aims to improve livelihoods while simultaneously reducing deforestation.

Furthermore, this research demonstrates that dependence on forest resources and agricultural production in forested landscapes can improve households' livelihoods. However, increased forest extraction and agricultural land expansion affect resource sustainability, though the impact of these factors varied across landscapes and along the Miombo forest transition gradient. For instance, in the early and late forest transition regions (North-Western and the Eastern Province), we found that improvement in households economic attributes (i.e., land and non-land-based income) reduced deforestation. In contrast, in the mid forest transition region (Copperbelt Province), improvement in economic attributes greatly had adverse effects on deforestation.

Notably, we observed that crop productivity affects deforestation differently across distance categories from households (homesteads), which also varied along the forest transition gradient. This finding confirms partly our hypothesis suggesting that *agricultural land use can be associated with distances to settlements and deforestation* (Angelsen, 2007). However, this result does not support the views that suggest *higher deforestation patterns closer to settlements (processing centres) can be associated with high return crops (commercial crops)* (see von Thünen, 1826). This result implies that crop productivity does not consistently relate to distance categories and along the forest transition. This means that the patterns of deforestation in the Miombo woodlands are mainly subsistence driven and, thus, independent from return-related deforestation patterns. Even though this finding indicates that the von Thünen (1826) theory does not apply in agrarian economies with limited market depth. On the other hand, the result implies that the economic impact of distances to settlements can complement the forest transition effects.

The practical implication of our findings (i.e., policymaking and forest programme designs) is that the economic costs and benefits associated with household processes such as investments in education, land and non-land-based income activities are critical aspects of policy legislation and forest design management approaches. For instance, we found that households with better education levels had lesser incentives to participate in forest support programmes. Moreover, a higher share of household incomes (forests, crops and non-farm incomes) reduced the likelihood of participation in forest support programmes.

Other factors that were important but negatively affecting participation include landholding size, distances to markets, forestlands and location of households. These results do not wholly confirm our hypothesis, *"household-level factors affect participation in forest support programmes differently"*. Rather the findings demonstrate a directional outcome suggesting that improvements in rural households' social and economic aspects negatively impact participation in forest support programmes. This result implies that higher opportunity costs associated with specific household activities are important determinants of household decisions regarding participation in forest support programmes. Thus, we recommend that policies and interventions aimed at improving livelihoods must target resource-poor households with limited incomes, lower education, and little access to markets in the forested landscapes. Furthermore, forest programmes must provide farm input support while promoting reforestation and agroforestry techniques.

7. Literature

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8. List of publication of the author

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3. Kazungu, M., Zhunusova, E., Kabwe, G., Günter, S (2021). Household-Level Determinants of Participation in Forest Support Programmes in the Miombo Landscapes, Zambia. *Sustainability,13(5), 2713*. doi: https://doi.org/10.3390/su13052713

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10. Appendix

10.1. Publication 1

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Forest use strategies and their determinants among rural households in the Miombo woodlands of the Copperbelt Province, Zambia

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ABSTRACT

Forest landscapes in tropical and subtropical areas support the livelihoods of their inhabitants through subsistence use of products, and cash income obtained from the sale of products. Despite its contribution to livelihoods, it remains unclear how forest products play a role in forest use strategies and what affects different forest use strategies, particularly in rural tropical Africa. A better understanding of forest-based livelihood strategies could be an important basis for the design of sustainable development policies. In this study, we use cluster analysis to identify forest use strategies and apply multinomial logistic regression to determine the factors affecting forest use strategy choices using data from 412 households in four sites in the rural Copperbelt province.

Results reveal three strategic forest use choices undertaken by households: specialised charcoal sellers (32.3%), forest food and charcoal sellers (18.2%) and pure subsistence-orientated forest users (49.5%). Forest income varied strongly among forest use strategies; specialised charcoal sellers and forest food and charcoal sellers were the most remunerative strategies. We observed higher per capita extraction of firewood and charcoal produced in restricted landscapes compared to non-restricted landscapes. Distances to exclusively owned forestlands, access to permanent roads, restrictions on public forestlands and off-farm incomes were found to determine access to more lucrative forest use strategies. Alternatively, households with relatively older heads and larger sizes are associated with lower income (subsistence) strategies.

The results suggest the need for the efficient enforcement of restriction regimes, but also the benefit of understanding forest resource governance. Charcoal production is a more remunerative forest use strategy for rural households and a relatively resource-intensive yet important component of the rural economy. In order to ensure sustainable production, the demand for charcoal should be compatible with Miombo's production capacity. Sustainable production can be achieved by introducing reforestation or coppicing systems that are consistent with the growing demands of Miombo.

1. Introduction

Forests are renewable resources and how they contribute to human well-being depends on social management and natural resilience (FAO, 2005; Herdiansyah et al., 2014). Despite the importance of forests, especially to rural households in tropical and sub-tropical countries, they are often under threat by ongoing landscape changes (Keenan et al., 2015). Changes are triggered by proximate and underlying factors which include mainly agriculture and markets (Babigumira et al., 2014); fuelwood production (Kiruki et al., 2017); demographic factors (Handavu et al., 2019); conservation interventions (Saw and Kanzaki, 2015), and evolving pressures and opportunities (Jiao et al., 2017). Increasingly changes, mostly observed in tropical and subtropical countries (Sloan and Sayer, 2015), have attracted scholarly attention

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(Babigumira et al., 2014; Rasmussen et al., 2017). Forest landscape dynamics are also core themes with government and forested landscape policy think-tanks such as UNFCC conference of parties (COP), and the reduction of emissions from deforestation and forest degradation (REDD+) policies (Angelsen and Rudel, 2013; Day et al., 2014; Krishnaswamy and Hanson, 1999). Forest landscape changes align with global forest use and the management discourse that underline the significance of conservation policies promoting ecosystem services relating to rural livelihoods (Kalonga and Kulindwa, 2017; Stickler et al., 2017; Wunder et al., 2014).

In the tropics, where about 800 million people continue to derive livelihoods from forests and woodlands (Chomitz et al., 2007), the diverse use of forest products can in some cases form an essential livelihood strategy (Angelsen et al., 2014; Jones et al., 2016; Khundi et al., 2011). Nonetheless, recent forest and livelihood studies have often concentrated on the overall contribution of forest products to households, without explicitly categorising households on the basis of forest product use and cash needs despite possible synergies and trade-offs between forest subsistence and cash outcomes (Ali and Rahut, 2018; Dokken and Angelsen, 2015; Nguyen et al., 2015; Porro et al., 2015; Torres et al., 2018).

Forest products are collected mainly for household subsistence purposes in the most rural areas of the tropical countries (Dewees et al., 2010; Dokken and Angelsen, 2015; Langat et al., 2016), although some households also engage in collection for commercial purposes (Jones et al., 2016; Smith et al., 2017). Other studies highlighting the contribution of forest products to households have shown the importance of various forest products to the subsistence and cash needs of rural households (Angelsen et al., 2014; Belcher et al., 2015; Kalaba et al., 2013a; Shackleton et al., 2008). However, these studies do not explain the role forest products play in forest use strategies in rural households.

Although forests support millions of people who live primarily in tropical and sub-tropical forests and woodlands (Chomitz et al., 2007; Dokken and Angelsen, 2015), the contribution of forests to rural households is threatened by unsustainable exploitation methods. Often due to the clearing of land for agriculture (Gibbs et al., 2010), and demand for fuelwood in urban areas (Baumert et al., 2016; Zulu and Richardson, 2013). For example, the growth of small towns and cities in the Copperbelt province of Zambia has put pressure on the Miombo's Mwekera and Katanino forest reserves (CSO, 2012; Handavu et al., 2019; Kalaba et al., 2013a). The growing population accelerates pressure on the forests without a corresponding growth in household wealth; this leads to unsustainable forestland exploitation for fuelwood and agriculture (Leblois et al., 2017; Tembo et al., 2015). In general, this results in deforestation (Syampungani et al., 2009), and degradation of the forests (Sedano et al., 2016; Sulaiman et al., 2017). It is, therefore, essential to better understand household dependencies on forests, based on forest products harvested and consumed, but also to understand local perspectives providing context and a frame of reference for those forested landscapes (Shriar, 2014).

In Zambia's Copperbelt province, households show significant differences in how they use and benefit from forest product harvesting (Mulenga et al., 2017; Mulenga et al., 2014). The use of forest products is related to households' subsistence and cash tendencies (Kalaba et al., 2013a; Mulenga et al., 2014), but also driven by shocks and stresses (Kalaba et al., 2013b). Subsistence and cash benefits derived from forest product use may depend on emerging opportunities and household capital endowment, including human and social capital (Handavu et al., 2019), physical and financial capital (Bwalya, 2011; Mulenga et al., 2017), and other assets such as infrastructure, power, and institutions (Wolfersberger et al., 2015). On the other hand, external pressures present an ever-increasing demand for forest products, mainly in the form of the urban demand for cheap energy (Tembo et al., 2015; Zulu and Richardson, 2013) and forest food (DeFries et al., 2010; Rowland et al., 2017).

Studies on forest use and livelihoods can often be limited to describing activities that represent a combination of livelihood strategies such as agriculture or characterised as low-skilled and highly-skilled livelihood strategies (Angelsen et al., 2014; Nguyen et al., 2015; Soltani et al., 2012). Yet generalising activities that contribute to rural livelihoods eventually results in a lack of understanding of the livelihood contribution of the various forest products, especially to rural people living within or close to the forests (Sunderland et al., 2017).

There are limited quantitative empirical studies that have attempted to show a diverse picture of how households use forest products, especially for forested landscapes in Zambia. Categorising households based on their forest product use provides an understanding of forest-based livelihood strategies (forest use strategies) among people inhabiting in the Miombo woodlands (Dewees et al., 2010); this is especially important for Zambia because forests occupy about 66% of its land area (Kalinda et al., 2013) and offer livelihoods to most rural inhabitants (Chidumayo and Gumbo, 2010; Jumbe et al., 2008; Kalaba et al., 2013a; Mulenga et al., 2014). Categorising households based on their forest product use provides a more comprehensive picture of use strategies among rural households in Miombo woodland landscapes, which is important for targeted policy action (Wunder et al., 2014). In this study, we have taken a three-way approach to understanding the role of the forest products in the household forest use strategies, evaluating factors that affect forest use strategy choices. Firstly, the study seeks to define forest use strategies by establishing forest products and their monetary values in Copperbelt rural areas. Secondly, the study identifies the factors that affect each forest use strategy with a specific focus on the five capitals: natural, human, social, economic and physical. Thirdly, we analyse forest income across distinct forest use strategies.

2. Conceptual framework

2.1. Forest use strategy choices of rural households

In recent years, both scholars and development practitioners have applied and used a Sustainable Livelihood Approach (SLA) to understand livelihood strategies for rural households (Ashley and Carney, 1999; Scoones, 1998). Recent studies on forests and livelihoods have applied SLA to understand rural livelihoods, their linkages with factors shaping rural household behaviour that rely on natural resources in tropical countries (Babulo et al., 2008; Nguyen et al., 2015; Soltani et al., 2012). Our study draws on the broader "livelihoods conceptual framework" (Ashley and Carney, 1999; Scoones, 1998) to describe forest use strategy choices among households in the Copperbelt Province of Zambia. Chambers and Conway (1992) describe a livelihood strategy as the "capabilities, assets and activities required for a livelihood." A conceptual framework for livelihoods constitutes livelihood capital, livelihood strategies and livelihood outcomes (Fig. 1). The livelihood capital provides the basis for how households make livelihood choices. The capital can either be based on natural capital, such as forests, water, and agricultural land, or household capital consisting of human, social, financial and physical capital (Babulo et al., 2008; Nguyen et al., 2015). Based on the capabilities and endowments of the household, as well the prevailing opportunities, a household will use a combination of livelihood capital to either diversify for subsistence or engage in production for cash generation (Jones et al., 2016; Kalaba et al., 2013a; Mwitwa and Makano, 2012). Livelihood strategies, however, are also affected by factors beyond household control, such as shocks and infrastructure (Angelsen et al., 2014). For example, shocks affect capital, flooding affects road access, and livestock disease outbreaks affect animal assets. Thus, any choice of livelihood strategy selected by the household results in the desired set of livelihood categories, such as a high income (Nielsen et al., 2012) or a high capacity to cope with shock (Kalaba et al., 2013b), which, in turn, affect some livelihood capitals. For example, investments into capital assets or the education of household members.

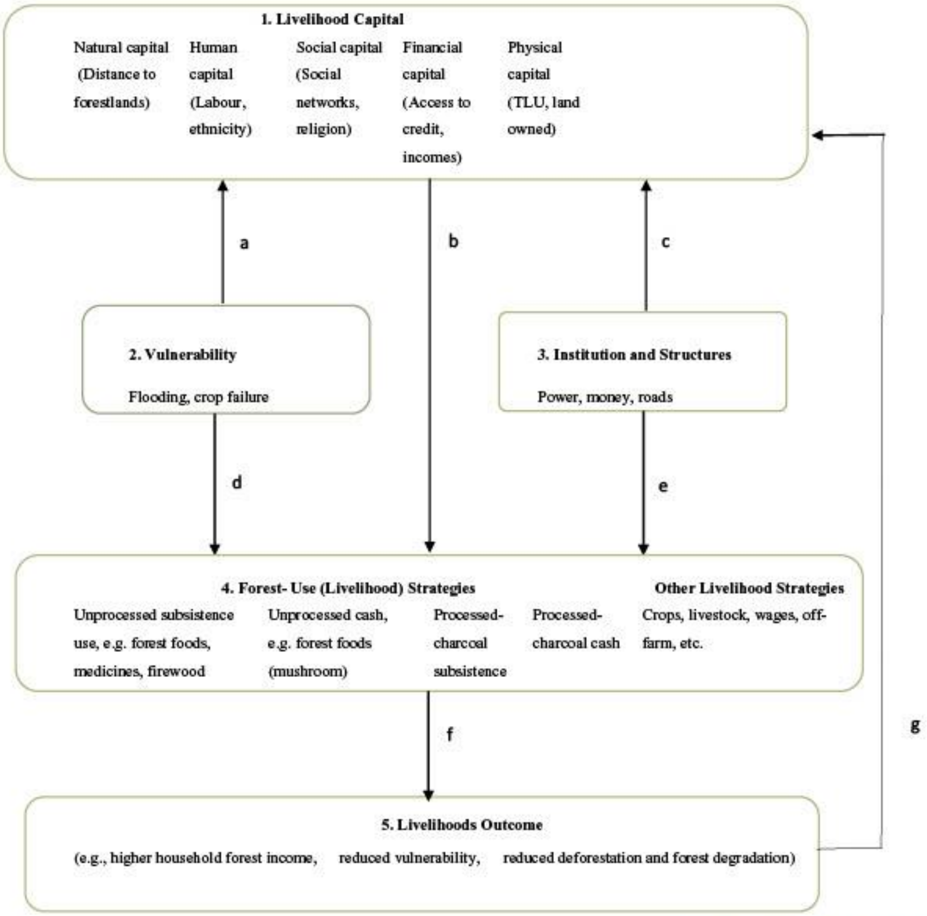

Fig. 1. A conceptual framework for the analysis of forest use (livelihood) strategy choices. *Source:* Modified from Ashley and Carney (1999) and Scoones (1998). The arrows show the direction of influence, e.g. Arrow B shows that livelihood capitals (Box 1) influence forest strategies (Box 4).

2.2. *Forest use strategy choices in the Miombo woodlands of Zambia*

The Miombo woodlands occupy about 45% of Zambia's forestland (Kalinda et al., 2013) and are a major source of livelihood for rural households (Kalaba et al., 2013a; Mulenga et al., 2014). The Miombo woodlands provide a wealth of species diversity (Frost et al., 2003), and a range of extractive products (Chinsembu, 2016; Handavu et al., 2019; Syampungani et al., 2009) to its inhabitants. It is estimated that the Miombo woodlands' contributions to total household income for households range from 35 to 43.9% (Kalaba et al., 2013a; Mulenga et al., 2014).

The Miombo products are consumed either in unprocessed or processed form. Unprocessed products form the bulk of household consumption needs, meaning subsistence use of forest products; these include wild plants, fruits, edible insects, honey, mushrooms, roots, tubers, and edible leaves (Handavu et al., 2019; Shackleton et al., 2010). Despite the low monetary value of subsistence forest products, their contribution to food security for households underlines their importance among rural households in Zambia. On the other hand, processed forest products including charcoal (Jones et al., 2016; Tembo et al., 2015), and timber and bark products, such as medicinal plants, are primarily processed for cash generation in households (Banda et al., 2007; Campbell et al., 2008; Chinsembu, 2016; Chungu et al., 2007).

The Miombo forest products are mainly harvested from public forestlands that include forest reserves (Kalinda et al., 2008), and private forests (exclusively owned forestlands) (Chitonge et al., 2017). Given that use of forest resources is entwined in most people's culture (Chidumayo and Gumbo, 2010; Syampungani et al., 2016), there is a high reliance on forest products the Miombo woodlands (Dewees et al., 2010; Kalaba et al., 2013a). However, high deforestation rates estimated at 0.5–0.6% of total forest cover (i.e. 250,000–300,000 ha/year) (FAO, 2015), and forest degradation threaten the Miombo's integrity and consequently its provisional ability (Chidumayo, 2013; Syampungani et al., 2009). Forest product assessments offer us the means to assess the quantitative contribution of the forest products to rural livelihoods, but also to understand the volume of forest products that households extract from forest landscapes.

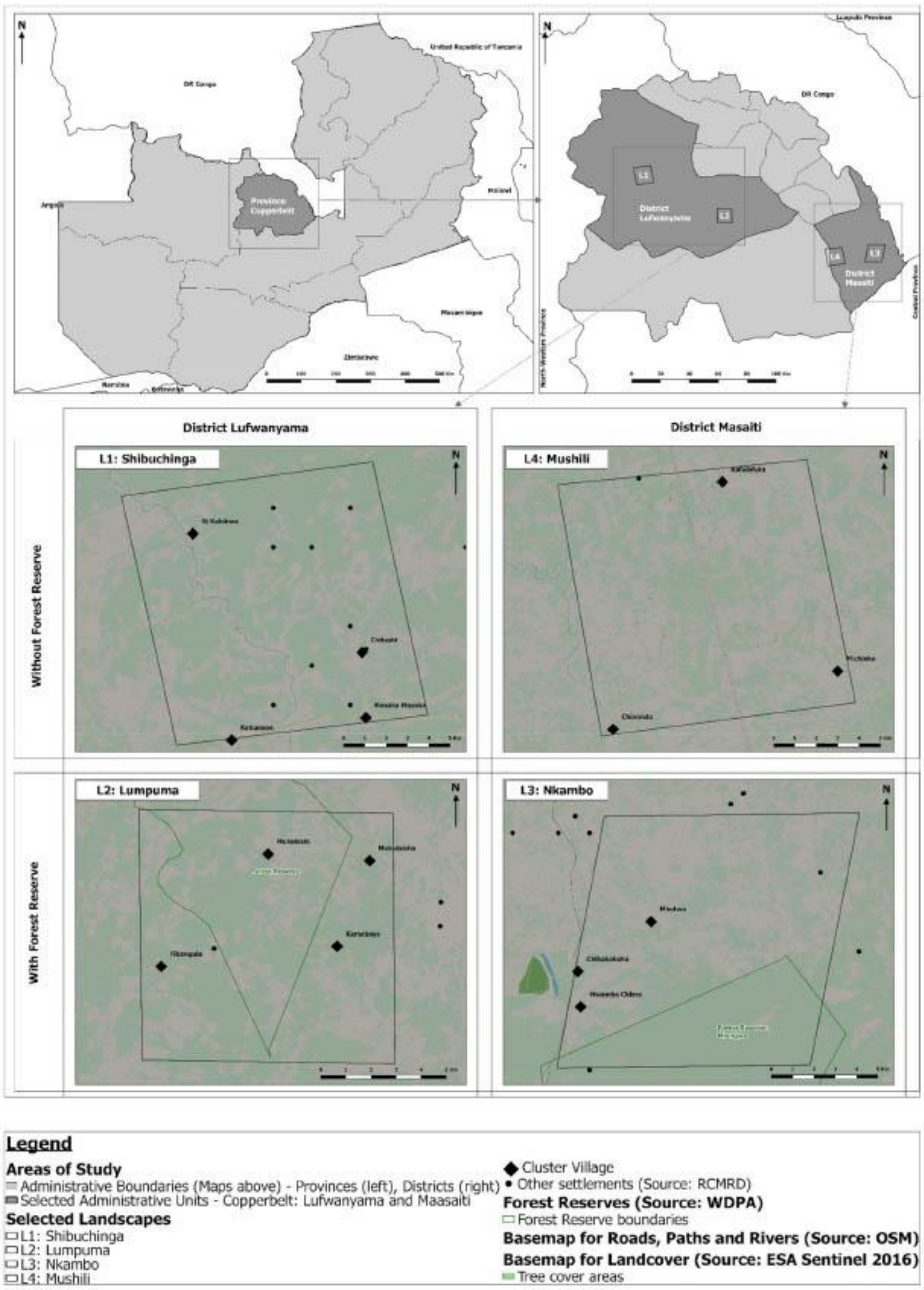

Fig. 2. Map of Zambia (top-left), Copperbelt Province (top-right), and study landscapes (below) in Lufwanyama and Masaiti district.

Table 1
Spatial characteristics of the four landscapes in the study area.

District	Chiefdom-landscape	Restriction in use	[1]Forest Reserve	[2]Total area [km^2]	[3]Restricted area [km^2]	[4]Forest ('TA') 2016 [km^2]	[5]Forest ('TA') restricted 2016 [km^2]	[6]Roads [km] ([km/ km^2])	[7]Population [pers.] ([pers./km^2]) 2015
Lufwanyama	Shibuchinga	Non-restricted	–	142.59	–	86.87 (60.92%)	–	42.78 (0.30)	950 (6.66)
Lufwanyama	Lumpuma	Restricted	Lamba block C	144.45	47.68 (33.01%)	81.04 (56.10%)	28.20 (34.80%)	40.45 (0.28)	861 (5.96)
Masaiti	Nkambo	Restricted	Miengwe	139.70	35.29 (25.26%)	73.72 (52.77%)	33.71 (45.73%)	135.51 (0.97)	2358 (16.88)
Masaiti	Mushili	Non-restricted	–	139.18	–	55.74 (40.05%)	–	144.75 (1.04)	1880 (13.51)

[1] Name of the forest reserve (IUCN and UNEP-WCMC, 2016).
[2] Total area of the landscape (no buffer included).
[3] The percentage of protected area within the landscape (IUCN and UNEP-WCMC, 2016).
[4] Area of tree-cover vegetation (i.e. tree-cover areas (TA) in the landscape. The percentage represents TA compared to the total area of the landscape (ESA, 2017).
[5] The percentage of restricted forest (i.e. protected TA) compared to the total forest area in the landscape (ESA, 2017).
[6] Estimated road density existing within the landscape area is calculated with a 5 km buffer. The total roads in km were extrapolated within landscape boundaries (OpenStreetsMap, 2019) and (self-digitisation).
[7] The total number of inhabitants was extrapolated within landscape boundaries, and estimated population density calculated with a 5 km buffer (Linard et al., 2012).

3. Material and methods

3.1. Study area

The Copperbelt Province is one of ten provinces in Zambia (CSO, 2012) (Fig. 2) and is situated on the Central African plateau, also known as the Miombo woodlands. The province is located at an average elevation of 1200 m above sea level and receives an annual rainfall of about 1200 mm, with temperatures ranging from 17 °C to 31 °C (MTNER, 2010). These climatic conditions give rise to three distinct seasons in the Copperbelt. The hot-wet season is from December to April; the cold-dry season from May to August; and the hot-dry season from September to November (Syampungani et al., 2010). The Copperbelt province covers a total area of 31,328 km^2, representing about 4.2% of Zambia's total area (CSO, 2014). The Central Statistics Office (CSO) (2012), estimates the population of the Copperbelt Province at 1,972,317 people of which 376,861 live in the rural areas and deriving livelihoods from the Miombo woodlands (Handavu et al., 2019; Kalaba et al., 2013a).

The Miombo woodlands are characterised by a high abundance of trees of the genera *Brachystegia*, *Julbernadia*, and *Isoberlinia* (Timberlake et al., 2010), which mainly provide wood for the production of charcoal (Kalaba et al., 2013c). The main charcoal species preferred by Miombo inhabitants are *Isoberlinia angolensis*, *Julbernadia paniculata*, *Brachystegia boehmii*, *Brachystegia floribunda*, and *Parinari curatellifolia*. Except for *Parinari curatellifolia*, all charcoal species are used for firewood (Syampungani, 2009). Despite differences in the use of Miombo forest resources, charcoal and firewood species in Miombo are prevalent throughout Zambian forest landscapes (Kalinda et al., 2013). In the Copperbelt province, 1.89 million hectares of land is under forest cover. This province has the highest relative tree cover loss, estimated at 14% compared to the Luapula province (10%), the Western (9.4%), the Central (8.6%), and the Eastern province (5.6%). These form the top four regions responsible for about 52% of all tree cover loss in Zambia between 2001 and 2018 (Curtis et al., 2018; Hansen et al., 2013). Tree cover loss in the Copperbelt province is mainly influenced by clearing of land for agriculture, degazzetion of forest areas, charcoal production and urbanisation (MTNER, 2009; Tembo et al., 2015; Vinya et al., 2011). For example, Kalaba et al. (2013a, 2013b, 2013c) observed a high use of forest resources from the Katanino and Mwekera forest reserves in the Copperbelt while Mulenga et al. (2015) noted that about 16% of households in the Copperbelt province engaged in charcoal production, compared to other provinces which were estimated to be between 3 and 12%.

Administratively, part of the Copperbelt forest is traditionally or formally managed, and elsewhere is under unknown management (Kalinda et al., 2013). The forestlands are maintained in a dual system which recognises customary and state ownership of land (Chanock, 1985; Kalinda et al., 2008). These traditional structures and practices differ from one chiefdom to another, owing to traditional methods and practices derived over the long term (Chanock, 1985; Kalinda et al., 2008). However, in most cases, the Chief is the de facto overall administrator of all the land under his jurisdiction and often appoints the Sub-Chief (*Induna*) and the Head of the Village responsibility too (Chitonge et al., 2017). The state manages restricted forests, such as national parks, national forests and game management areas, in collaboration with the establishment of the chiefdom (GRZ, 1995).

3.1.1. Site selection

We selected the study sites (landscapes) through a systematic process that involved a literature review, use of satellite imagery, scoping visits, and semi-structured interviews with the district officials and Sub-Chiefs. We selected four landscapes that represent the variability of forest cover and population pressure of the Copperbelt province (Fig. 2). Each landscape selected covers an area of 12 × 12 km^2, and represents different regimes of restriction and non-restriction to access and use of forest resources (Table 1). The four landscapes selected include Shibuchinga and Lumpuma chiefdom in Luwanyama, and Mushili and Nkambo chiefdom Masaiti district; these chiefdoms form the administrative units to which the forestlands belong. Some of the forestlands, such as national parks, national forests, and game management areas, are under state authority, thus restricted from use. On the other hand, the non-restricted forestlands, such as communal lands, inherited and privately allocated landholdings, are administered based on local customs and traditions (Mulenga et al., 2015). Land in customary areas is, in most cases, managed by a single person on behalf of the group while the Chief's role is to regulate acquisition and land-use (Chileshe, 2005; Payne and Durand-Lasserve, 2012). Although there is a mixture of forestlands, each landscape has been categorised by the extent of the two types of regimes, with each arrangement being managed by one chiefdom (GRZ, 1995) (Fig. 2). Furthermore, in each landscape, we selected 3–4 village clusters (villages) and compiled a list of households for the selected villages.

3.2. Data collection

3.2.1. Household survey

The study conducted a household survey to capture information on the composition and demographics of households, land-use and assets, production and economic activities (farming, livestock and fisheries, off-farm and non-farm income), forest use, forest user groups, and forest policy instruments. We interviewed the key informants who were identified through a snowball method with village leaders and other persons considered knowledgeable in order to delineate villages, understand village structures, and the number of households that were available per village.

A sample size of 100 households was determined a priori for each landscape; this was the study's standard sample size for all landscapes. However, the number of households for which the sample size in each landscape was drawn ranged from 260 to 372 households. We used a random sampling method to select respondent households. We chose a simple random method to increase efficiency and reduce variance between samples (De Leeuw et al., 2012). To further minimise sample errors from non-response and absentee households, we selected five additional households in each village (if the originally selected households were not available). In conducting a random selection of households, we subsequently assigned distinctive numbers to households in the generated household roster; then the roster containing household numbers was shredded, folded, and put in a bowl/hat. We mixed the bowl's contents, and households were then selected randomly in a joint exercise by the researchers, a few village members and village leaders. The selection exercise was repeated several times until we achieved the assigned number of households for each village, and the method was replicated for all the study sites.

The study collected household data using a structured questionnaire administered by the research assistants. The main respondent was the head of the household, or alternately, any other adult person who had been living with the household for at least one year and was familiar with households' livelihood assets and land-use decisions. The study conducted household interviews in the local language; in the Copperbelt, primarily Bemba and Lamba. Household interviews lasted about an hour and thirty minutes. The interviews were conducted following guidelines for household interviews recommended by Angelsen (2011) for measuring livelihoods and environmental dependence. We asked about the quantity of crop production, livestock and forest products consumed and sold for the last twelve months. Given the restriction on harvesting certain forest products, such as the production of charcoal, hunting and other woody materials in restricted forest areas or any forest area (Forests Act, 2015), some operations are illegal and may be underreported in the household survey. This research cannot test or control this prospective bias in our data. However, we tried to limit any bias that would accrue during the data collection stage that involved scoping visits and household data collection. The study emphasised its neutrality at the hiring of the research assistants, and underscored to village leaders and households that our research group is not government associated. Finally, the research surveyed 412 households within the four landscapes selected in the Copperbelt province.

3.2.2. Household characteristics

In a particular setting, socio-economic and environmental factors influence household behaviour. Understanding the characteristics of households is an important step in analysing the livelihood choices of households, particularly forest use strategy choices (Angelsen et al., 2014). We assessed the characteristics of households such as forest access, market access, demographics and land-use patterns (Babigumira et al., 2014; Handavu et al., 2019; Mulenga et al., 2014), also see Appendix A Table A1.

3.2.3. The volume of firewood collected and charcoal produced

The volume equivalents produced for charcoal and firewood extracted in the study area were used to estimate the quantity of wood biomass extracted in the Miombo woodlands. The study randomly measured actual dry weights of firewood (headload) bundle, and charcoal (50-bag kg) in the different villages. Each product was weighed five times and the average weight calculated. For approximately 32 kg of charcoal produced in an earth kiln (Chidumayo, 1993), we applied a conversion factor of $9m^3$ per tonne (FAO, 1987), while for 23 kg (headload) of firewood, we applied a factor of $0.33m^3$ per tonne (Openshaw, 1983). The volume conversion enables a standard estimation of per capita consumption of firewood and charcoal in our study sites.

3.2.4. Calculating forest income

Our study captured real and perceived forest product prices through household interviews, village market surveys, and key informant interviews. We analysed the initial findings of the study to establish a list of forest products harvested by households. Later, we performed a separate price study to capture the perceived prices of some forest products that had no market value. The price survey targeted key forest product producers in the village markets and also performed group interviews with merchants at particular village markets. We surveyed five respondents from each village, selected via a two-step method involving consulting with village officials to identify initial participants and subsequently using a snowball method.

Forest income values were calculated as net income as defined in most environmental income studies (Angelsen et al., 2014; Dokken and Angelsen, 2015). Forest net income means subsistence or cash income from forest products minus the value of hired labour, marketing and transportation costs. As in previous studies, the value of own labour is not deducted from net income because it is not possible to establish suitable shadow labour prices in rural areas (Cavendish, 2012; Luckert and Campbell, 2012). Furthermore, forest income is adjusted to account for varying household size and composition (Handavu et al., 2019). We estimated the net forest income variable in adult equivalent units (AEU) (i.e. Kwacha/AEU); where adults aged between 15 and 64 are assigned a weight of one (1), and dependants below 15 and above 64 are assigned a weight of 0.5 (Dokken and Angelsen, 2015). Other variables, such as exclusively owned forestland (i.e. the household exclusively owns the forestland which includes both used and unused land) were also converted to AEU (ha/AEU) see Appendix A (Table A1).

3.3. Econometric model and estimation

3.3.1. Determining forest use strategy choices

To determine the forest use strategy choices which households adopted in the Copperbelt Province, we applied a cluster analysis on subsistence and the cash income derived from harvesting unprocessed and processed forest products. Through our study design, all households in the study sites had access to forestland (whether used exclusively or publicly or both), and we observed that all households used forest products in one way or the other. The differences in forest product use arise from the types and quantities of the products harvested, and the frequency with which each product is used. Based on the household's use of forest products, the clustering method assisted in categorising households into forest use strategies. Clustering households based on forest products, rather than all rural livelihood sources, enables a differentiated examination of forest-based livelihoods.

This study specifically applied k-means clustering on variables that represent value in the use of forest products. The k-means cluster algorithm is a partitional clustering method commonly used as an exploratory clustering technique (Hastie et al., 2005). When the number of clusters is unknown, several k-means solutions with a different number of groups k (k = 1, ..., K) are computed and compared (Makles, 2012). By applying the k-means algorithm on the total forest income, processed subsistence and forest cash income, and unprocessed subsistence and forest cash income, we are able to detect the clustering with the optimal number of groups, k from the set of K solutions. We used a scree plot and searched for a kink in the curve generated from within the sum of squares (WSS) (Makles, 2012). We chose the k-means clustering because of its ability to scale each column while minimising variability within clusters and maximising variability between clusters (Brown et al., 2006; Nguyen et al., 2015; Var, 1998). It can be applied in numerical data measured on the same units, and also data whose variables are captured in different units of measurement, thus helping to correct errors that could happen between different clusters (Soltani et al., 2012). Once the clustering was complete, a one-way ANOVA was performed on the results to make sure that the means in the independently categorised household clusters are different. While the chi-square (X^2) was performed to ensure that at least two clusters were statistically different (Dattalo, 2013).

3.3.2. Estimating the determinants of forest use strategy choices

Forest use strategies adopted by households, were identified by the categories determined by the cluster outcomes on forest income. The forest use strategy choices formed the basis for the Multinomial Logistic regression (MNL). The MNL is applied when the dependent variable is unordered and consists of multiple categories (Wooldridge, 2010). In our analysis, the cluster categories are independent of each other, implying that membership in one category is not related to the membership of another category. However, the categories cannot be perfectly separated, and are non-linearly related to independent variables; such relations are best analysed using MNL regression (Starkweather and Moske, 2011). Before performing the MNL, we checked for Multicollinearity using the Variance Inflation Factor (VIF) for all the independent variables, as shown in Appendix A (Table A1). And while performing the MNL, we used manual step-by-step elimination (Dattalo, 2013) of variables that showed $p > .5$ in both cluster categories.

Thus, our theoretical MNL model follows the framing as applied by Dehghani Pour et al. (2018):

$$\eta_{ij} = \frac{\exp(X_j' \beta_j)}{\sum_{l=1}^{m} \exp(X_i' \beta_l)}, j = 1, 2..., m$$

where η_{ij} is the model for the probability of household that shows that household i chooses a livelihood strategy j from m strategies, X_i is the vector for the explanatory variables associated with the i^{th} household, and $\beta_j = 0$ for the baseline. Thus the coefficients are interpreted with respect to the baseline strategy and estimated by the maximum likelihood method (Wooldridge, 2010). Following the SLA, the households' livelihood strategy choices can be derived from a livelihood's capital which encompasses five capitals (Fig. 1). Table A1 in Appendix A shows the explanatory (independent) variables used to model the structural relationship between forest use strategy choices and livelihood capitals. Non-productive fixed assets, such as owning dwelling unit/s, and small equipment, such as hoes, bicycles and radios, were excluded from the analysis because they showed no variability among rural households.

The empirical model is as follows:

$$\begin{aligned} \eta_{ij} = {} & \alpha_0 + \beta_1 dis_{for_{pub}} + \beta_2 dis_{for\_own} + \beta_3 fc_{los} + \beta_4 age + \beta_5 gender \\ & + \beta_6 hh_{size} + \beta_7 educ + \beta_8 ethnic + \beta_9 mobphone + \beta_{10} migration \\ & + \beta_{11} credit + \beta_{12} cropinc + \beta_{13} livinc + \beta_{14} off_{farm} + \beta_{15} self_{empl} \\ & + \beta_{16} remi + \beta_{17} TLU + \beta_{18} land_{owned} + \beta_{19} dis_{mainroad} \\ & + \beta_{20} access_{road} + \beta_{21} incomeshock_{crop} + \beta_{22} assetshock_{livestock} \\ & + \beta_{23} labour_{illness} + \varepsilon_i \end{aligned}$$

where η_{ij} shows the probability of household i choosing strategy j, and definitions of the independent variables are given in Appendix A (Table A1).

4. Results

4.1. Descriptive results

4.1.1. Socioeconomic and environmental characteristics of households

Table 2 shows a summary of the characteristics of the households in the Miombo woodlands of the Copperbelt. The results reveal that households walked shorter distances to exclusively owned forestlands (forestland exclusively owned by households) (i.e. 1.3 km) than to public forestlands (communal areas, and state lands) (i.e. 1.9 km). A further assessment of the forestlands reveals that households in the rural Copperbelt own an average of 9.6 ha of land translating to 2.3 ha per AEU (Table 2). These rural areas are characterised by a lack of access to permanent roads, restricted use rights of public forestlands, and longer distances to the village centres (Table 2). While other capitals, i.e. human, and social capital, reveal a patriarchal inclination, as 88% were male-headed households, and the largest group (49%) was part of the Lamba tribe. The average size of a household is 4.5 in AEU with heads of the households, mainly attaining primary level education (Table 2).

4.1.2. Description of households' income sources

The study also analyses the relative contribution of various income sources to total households' income (share of income attributed to different sources) (Table 3). The relative contribution of forest income to households is analysed and discussed in relation to other rural household income sources. Forest products (i.e. unprocessed and processed) by far contributed the largest share of household income (54.1%) compared to other rural income sources. Processed products, mostly charcoal, accounted for 37.4% of total household income in the rural Copperbelt (Table 3). On the other hand, agricultural income (crops, livestock and fish) contributed to 33% of the share of total household income, while crop production is the second highest income source contributing 23.4% of the share of the total income in the rural Copperbelt (Table 3). Unlike forest products and agriculture, the contribution of other income sources to households' total income was low and estimated at 12.9% (Table 3).

The contribution of processed and unprocessed forest products to household cash and subsistence needs are presented in Table 4. Processed forest products provided higher forest income (69.1%) compared to non-processed forest products. Charcoal was the most extensively processed forest product providing a higher income compared to other forest products. These results suggest that charcoal is an important economic livelihood component of charcoal processing households. Unprocessed forest products mainly contributed to subsistence needs; these products most commonly included firewood and forest foods (i.e. mushrooms, honey, beverages and wild animals) (Table 4).

Table 2
Characteristics of the households in the study area (n = 412).

Variable description	Mean ± SD*
Natural capital	
Walking distance from household to public forestland (km)	1.9 ± 1.6
Walking distance from household to exclusively owned forestland (km)	1.3 ± 1.3
**Forest cover loss observed by household in the last five years (1/0)	85%
Household participates in charcoal production (1/0)	50%
Human capital	
Ages of the head of household (years)	45.1 ± 14.0
Gender of the head of the household (1-male / 0-female)	88%
Household (HH) size (number of people)	5.9 ± 2.5
Household (HH) size - adult equivalent unit (AEU)	4.5 ± 1.9
Head of the household education (1-high school and above / 0)	25%
Social capital	
Head of household belongs to the largest ethnic group - Lamba (1/0)	49%
Number of phones in the household (number)	1.1 ± 1.0
Duration of residence in the village (years)	16.1 ± 13.6
Financial capital	
***Total household income (kwacha) - per capita	5934.6 ± 11,025.7
Household accessed credit in the last one year (1/0)	20%
Physical capital	
Tropical livestock unit (TLU)	1.8 ± 4.5
Size of land owned by household (ha)	9.6 ± 12.6
Size of land owned by household (ha^{-AEU})	2.3 ± 3.3
Infrastructure (exogenous)	
Access to road usable throughout the year (1/0)	33%
Household walking distance to the main road (Km)	4.2 ± 4.9
Vulnerability (exogenous)	
Income shock-crop failure in 2017 season (1/0)	72%
Asset failure-livestock loss (1/0)	26%
Labour loss - an illness of a member of the family (1/0)	31%
Labour loss - the death of a member of the family (1/0)	12%

All income values are calculated in Zambian Kwacha (ZMW). At the time of the study, 1 USD = 10.13 ZMW (Bank of Zambia, 2018). One household has a negative total household income; this could have been because of high production costs and crop failure, or livestock loss, this household is not included in the descriptive analysis and subsequent calculations that follow. The sample size is, therefore reduced from 413 to 412 households.

* SD is the standard deviation.

** Miombo is reported to have high woodland recovery after felling (Chidumayo, 2004; Syampungani et al., 2016).

*** Income is measured in net value and analysed in relation to adult equivalent (AEU) per capita as applied by Dokken and Angelsen (2015).

Table 3
Distribution of household income by source in the study area (n = 412).

*Income sources (Zambian kwacha) (ZMW)	Mean ± SD	Share of total sample income (%)
Unprocessed forest product income	994 ± 1259	16.7
Processed forest product income	2222 ± 8272	37.4
Subtotal: Forest products income		54.1
Crop income	1390 ± 4670	23.4
Livestock income	563 ± 1261	9.5
Fish income	8 ± 26	0.1
Subtotal: Agriculture income		33.0
Off-farm income	39 ± 189	0.7
Self-employment	515 ± 3575	8.7
Remittances income	71 ± 312	1.2
Wage income	133 ± 664	2.3
Subtotal: Other incomes		12.9
Total household income	5935 ± 11,026	100

* Income is measured in net value divided by the AEU and is calculated in Zambian Kwacha (ZMW) per capita. At the time of the study, 1 USD = 10.13 ZMW (Bank of Zambia, 2018).

4.1.3. Volume equivalents of firewood and charcoal

In restricted forestland landscapes, the per capita consumption of fuelwood (i.e. firewood extracted and charcoal produced) is $1.61m^3$ ($1.61m^3$/year/AEU) higher than in non-restricted landscapes (Table 5). Nevertheless, we found that in both restricted and non-restricted landscapes, higher volumes of charcoal per capita were produced relative to firewood (Table 5).

When we compare extracted volumes of firewood and charcoal produced within each landscape, the per capita volume of charcoal produced is $3.8m^3$/year/AEU, and $2.21m^3$/year/AEU higher than the per capita volume of firewood extracted in the restricted and non-restricted landscapes (Table 5). For households obtaining forest products only from exclusively owned forestlands, the per capita volume of charcoal produced in restricted ($1.75m^3$/year/ha)[a] and non-restricted ($1.06m^3$/year/ha) landscapes would be much higher than the per capita volume of firewood extracted in restricted ($0.1m^3$/year/ha) and non-restricted ($0.09m^3$/year/ha) landscapes.

Therefore, restricted landscapes of the Copperbelt provided higher per capita volumes of charcoal and firewood than non-restricted landscapes. However, the difference in per capita consumption observed across households show higher volumes of charcoal produced both in restricted and non-restricted landscapes relative to firewood. Our finding supports results from Tables 3 and 4 that indicate charcoal as a forest activity of high income relative to firewood, which is mainly for subsistence purposes.

4.2. Econometric results

4.2.1. Description of households' forest use strategy choices

The scree plot in Appendix A (Fig. A1) shows that three k-means clusters best explain forest use strategy choices in the Copperbelt province. The three forest use strategy choices are pure subsistence-orientated forest users, specialised charcoal sellers, and forest food and charcoal sellers (Table 6). Pure subsistence-orientated forest users make up Cluster One (1), consisting of 49.5% of households in the study area. Cluster Two (2) is made up of specialised charcoal sellers and comprises of 32.3% of households in the study area. While Cluster Three (3) consists of 18.2% of households and includes forest food and charcoal sellers. Cluster One households earned a lower income from collecting forest products than Clusters Two and Three (Table 7). On the other hand, Cluster Two households earned higher income from charcoal sales than Clusters One and Three. However, there is no statistical difference between Cluster Two and Cluster Three in the amount of income from charcoal production (Table 7). Yet, Cluster Three households earned higher forest food sales income than Cluster Two households (Table 7). Clusters Two and Three are both households involved with charcoal production, which together account for up to 50.5% of study households, thus suggesting the importance of charcoal production to the rural economy, especially for the province of Copperbelt.

Table 7 illustrates the type of forest income and the contribution of primary forest products to each forest use strategy choice. The chi-square (X2) shows statistically different forest incomes in at least two clusters. For example, a forest income in Cluster One is statistically different from Cluster Two and Cluster Three and vice versa. The ANOVA test also reveals cluster income differences. For example, the total unprocessed forest income of Cluster One differs significantly from Cluster Two and Cluster Three (Table 7). Generally, the variance in the forest use strategy choices depended on whether the household was subsistence or cash-orientated. Subsistence-orientated forest users collected and used mainly firewood and forest foods; these were less remunerative activities, while charcoal was the most remunerative activity (Table 4).

4.2.2. Determinants of households forest use strategy choices

The MNL regression results (Table 8) support the cluster analysis presented in Section 4.2.1., that households in the Miombo woodlands

Table 4
Main forest products providing subsistence and cash income in the study area (n = 412).

Variable	Processed		Unprocessed	
	Mean ± SD	Share of total forest income (%)[a]	Mean ± SD	Share of total forest income (%)[a]
Subsistence forest income (total)	148.2 ± 620.8	4.6	916.2 ± 1187.0	28.5
Charcoal subsistence income	144.4 ± 618.4	4.5		
Forest foods subsistence income (mushrooms, fruits, beverages, honey, animals)	2.8 ± 42.6	0.1	490.3 ± 826.1	15.2
Structures and fibres subsistence income (poles, thatch-grass, fibre, timber)	1.0 ± 9.7	0.0	54.2 ± 117.0	1.7
Firewood			369.1 ± 394.4	11.5
Medicines			1.2 ± 5.2	0.0
Other forest products subsistence income			1.3 ± 7.4	0.0
Cash forest income (total)	2074.1 ± 7800.7	64.5	77.9 ± 275.1	2.4
Charcoal income	2029.8 ± 7786.2	63.1		
Forest foods income (mushrooms, fruits, beverages, honey, animals)	29.0 ± 257.8	0.9	77.5 ± 275.0	2.4
Structures and fibres cash income (poles, thatch-grass, fibre)	15.3 ± 213.1	0.5	0.1 ± 1.3	0.0
Firewood			0.1 ± 1.3	0.0
Medicines			0.0 ± 1.0	0.0
Other forest products subsistence income			0.2 ± 1.5	0.0
Absolute value (ZMW)[b]	2222.4 ± 8271.6	69.1	994.0 ± 1258.6	30.9

[a] The share of total forest income is calculated by dividing mean income per source for the whole sample, by total forest absolute value (i.e. processed plus unprocessed incomes).
[b] All income values are in AEU per capita and measured in Zambian Kwacha.

of the Copperbelt are pursuing different forest use strategy choices with respect to the capital available to them. The effects of independent variables on forest use strategy choices of households are analysed with the most common forest use strategy; pure subsistence forest users as the reference category (Table 7). The positive coefficients in the MNL regression (Table 8) thus indicate that the independent variables positively relate to the probability of being in the cluster concerned (i.e. Cluster Two or Cluster Three), while the negative ones support the reference category. For example, longer distances to public forestlands increase the likelihood of households belonging to Cluster Two and Three relative to Cluster One, while increasing distances from exclusively owned forestlands reduce the possibility of households belonging to Cluster Two and Three relative to Cluster One. Regarding the general fit of the model, the global chi-square, the associated p-value and R-square indicate that the model is significant (Table 8); this implies that independent variables in the model explain, to some extent, the variances observed in the forest use strategy choices.

Furthermore, the MNL results (Table 8) reveal different effects on each forest use strategy choice. However, both specialised charcoal sellers and forest food and charcoal sellers are affected by distances to public and exclusively owned forestlands and a lack of access to permanent roads. On the other hand, results show that households with a small household size are less likely to belong to Cluster Two compared to Cluster One. Similarly, households with ageing household heads are less likely to belong to Cluster Three relative to Cluster One. Adding to the salience of this analysis is the effect of increasing off-farm income on the likelihood of households belonging to Cluster Three relative to Cluster One (Table 8). Although the effect appears to be too small (i.e. 0.001 coefficient), this could be attributed, in part, to the high variance of rural income in the study area (Table 3).

We included landscape dummies in the model; whether the household belonged to a restricted or non-restricted landscape to control for spatial heterogeneity with Cluster One (pure subsistence-orientated forest user) as a base category, and the findings demonstrate that there is significant spatial variability. Compared to Cluster One, households in restricted landscapes are more likely to adopt forest food and charcoal sellers strategy, findings backed by the outcomes in Table 5, that the volume of forest products extracted from restricted landscapes was higher than that of non-restricted landscapes in the Copperbelt province.

5. Discussion

5.1. Main characteristics of households in the study crea

As noted in Table 2, households in the rural Copperbelt province remained closer to exclusively owned forestlands relative to public forestlands and had an average of 2.3 ha of land per AEU (the average size of a household is 4.5 persons in AEU (Table 2)). As reported elsewhere, about 60% of the households in Zambia use mainly hand-hoes for farming (Haggblade and Tembo, 2003). In highly populated provinces, such as the Copperbelt and Lusaka, it is estimated that households are able to cultivate pieces of land ranging from 1.38 to 3.5 ha compared to other low populated provinces (0.25 ha per household) despite low labour productivity (CSO, 2012; Handavu et al., 2019; Mulenga et al., 2017; Shakacite et al., 2016). However, with the exception of areas lost due to slash and burn agriculture (Syampungani et al., 2016), arguably uncultivated forestland is used as a source of forest products to meet household food and cash needs (Jones et al., 2016; Kalaba et al., 2013b; Smith et al., 2017). Particularly as rural households live within exclusively owned forestlands which are characterised by mainly poor access to the permanent roads and markets (Table 2) (Dash et al., 2016). This finding suggests that areas that are highly populated clear more forestlands and are likely to use more forest products than areas with a low population (Ferretti-Gallon and Busch, 2014).

5.2. Description of households income sources

In this study, forest product harvesting was found to be one of the most important income sources adopted by rural households in the Copperbelt province (Table 3). The share of forest income for both processed and unprocessed to the total household income was 54.1%. Our results agree with other studies that found that the contribution of forest products to household income was higher than that of most sources of rural income (Jumbe et al., 2008; Kalaba et al., 2013a; Mulenga et al., 2014), although variations were observed across studies. The differences across studies were likely due to the different scopes and context of the research. Jumbe et al. (2008), for instance, reported their findings based on eight sites in three provinces, while Kalaba et al. (2013a) observed their findings based on a study performed at two sites in the province of Copperbelt. Consequently, these

Table 5
The quantities of charcoal, firewood, and volume equivalents per year per household in the study area (n = 412).

Description	[1]Average units collected/ year/hh (restricted landscape)	Average units collected/ year/hh (non- restricted)	[2] Unit	[3]Average kgs/ unit	Conversion factor (m^3/t)	[4]Volume m^3/year/hh (restricted landscape)	Volume m^3/year/hh (non- restricted)	[5]Volume m^3/year/AEU (restricted landscape)[a]	[6]Volume m^3/year/ AEU (non- restricted)
Firewood	138.9 (CI, 121.7–156.1)	129.4 (CI, 114.4–144.3)	Headload (Bundle)	23 ± 7.98	0.33	1.05	0.98	0.23	0.22
Charcoal	62.9 (CI, 47.7–78.0)	37.9 (CI, 25.4–50.4)	50-bag-kg + 'ball pen'	32 ± 3.11	9.00	18.12	10.92	4.03	2.43
Total						19.17	11.90	4.26	2.65

1. Confidence interval (CI) is taken at 95%. 2. The local unit used for measuring forest products in the study area. 3. Random weights of firewood and charcoal were taken at different locations of the study; in total, each product was weighed five times. 4. Volume per cubic metre per year per household (m^3/year/hh) is calculated by multiplying the average unit by average kgs, the result is converted to tonnes and then divided by a conversion factor (e.g. for a restricted landscape we have 138.9*23 kg = 3194.7 kg → 3194.7 kg = 3.1947 t → 3.1947*0.33 = 1.054 m^3/year/hh). 5, and 6. Cubic volume per year per person (AEU) (i.e. m^3/year/hh), calculated by dividing 4 by household size per AEU (4.5) (Table 2).
Source: Own calculation from household data survey (2017–2018).
[a] Note, assuming firewood extraction and charcoal produced are only obtained from exclusively owned forestland, 5 and 6 would be divided by 2.3 ha (Table 2).

Table 6
Forest livelihood strategies in the study area (cluster analysis).

Cluster	No. of HH	Per cent (%)	Main forest-livelihood strategies
1	204	49.5	Pure subsistence forest users
2	133	32.3	Specialised charcoal sellers
3	75	18.2	Forest food and charcoal sellers
Total	412	100	

Source: Own calculation from LaForeT household data survey (2017–2018).

discrepancies indicate that research still does not understand the economic significance of Zambia's forests, and this is an area for further study.

With regard to the contribution of specific forest products, our findings reveal that this varies depending on the products consumption form: processed or unprocessed (Table 4). Among processed products, charcoal was the main product with the largest share (37.4%) of total household income compared to other rural income sources (Table 3). Our result is confirmed in a study from Malawi by Smith et al. (2017), who observed that households were engaged in charcoal production because of the higher incomes associated with its production compared to other rural household sources (Jones et al., 2016; Kalaba et al., 2013b).

Forest products provide households with more subsistence and cash than any other income sources in the study area. Unprocessed forest products, such as firewood, forest foods, and structures and fibres (Table 4), contributed to 16.7% of the total household income and used for mostly subsistence purposes, findings corresponding to Mulenga et al. (2014), Kalaba et al. (2013a), and Hickey et al. (2016). However, our findings indicate a low use of forest products for medicinal purposes (Table 4), contrasting with results from previous studies that found higher use of medicinal plants in Zambia (Banda et al., 2007; Handavu et al., 2019; Ndubani and Höjer, 1999). The variations in study results are likely to reflect the methodology and context in which researchers performed their studies. For instance, Chinsembu (2016) documented the indigenous knowledge of medicinal plants among traditional healers, implying that knowledge on the use of medicinal plants is a reserve of traditional healers.

Similarly, Chungu et al. (2007), consulted traditional healers in studying the effects of bark removal for medicinal use. Their findings show that the use of medicinal plants is by a few knowledgeable people, referred to as "traditional healers". Our study was not able to test whether households were producers of medicinal plants or preferred going to the traditional healers, but our results (Table 4) indicate that the economic value derived from the use of medicinal plants is low as compared to use of other forest products.

Our study further reveals that the types of forest products vary across rural households as a result of variances in the households' capital (Ashley and Carney, 1999), household location (Ali and Rahut, 2018; Angelsen et al., 2014; Tugume et al., 2015), and the product season (Ellis, 2000). These factors may have caused the differences in the volumes of forest products collected. For example, we observe that the per capita production of charcoal and firewood extracted in restricted landscapes is higher than per capita volume of charcoal produced and firewood extracted in non-restricted landscapes, respectively (Table 5). These results correspond to Jagger et al. (2014) who in their global study, observed that households generate more forest income from state-owned forests than from private and community-owned forests.

5.3. *Description of households' forest use strategy choices*

The cluster results conform to the descriptive characteristics of households in the Copperbelt (Tables 3 and 4). Forest use strategies arise based on the capabilities of households and the various capitals at

Table 7
Cluster analysis for forest use strategy choices.

Variables	Whole sample (n = 412)	Clusters			X^2
		Pure subsistence forest users (1) (n = 204)	Specialised charcoal sellers (2) (n = 133)	Forest food and charcoal sellers(3) (n = 75)	
[Y]Absolute forest income	3216 ± 8833	$745^{2,3***}$ ± 940	5784^{1***3} ± 13,840	5386^{1***2} ± 7469	782^{***}
Unprocessed forest products income					
Total income	994 ± 1259	$745^{2,3***}$ ± 940	1239^{1***3} ± 1378	1237^{1***2} ± 1628	42^{***}
Subsistence income	916 ± 1187	678^{2***3*} ± 861	1239^{1***3} ± 1378	992^{1*2} ± 1434	46^{***}
Cash income	78 ± 275	67^{2*3***} ± 290	0^{1*3***} ± 0	$245^{1,2***}$ ± 388	10^{***}
Processed forest products income					
Total income	2222 ± 8272	$0^{2,3***}$ ± 0	4545^{1***3} ± 13,241	4149^{1***2} ± 6342	42^{***}
Subsistence income	148 ± 621	$0^{2,3***}$ ± 0	249^{1***2} ± 844	373^{1***2} ± 860	0
Cash income	2074 ± 7801	$0^{2,3***}$ ± 0	4296^{1***3} ± 12,545	3776^{1***2} ± 5794	46^{***}

[Y] Income values are in net value in AEU per capita and measured in Zambian Kwacha (ZMW). ± is the standard deviation. Superscript numbers show statistically significant differences between each respective cluster with other clusters (ANOVA test); *** significant at 0.01, ** significant at 0.05, and * significant at 0.1 levels. Note the international poverty line for Zambia is considered to be < 6.4 ZMW per day (World Bank, 2018).

the households' disposition (Ashley and Carney, 1999; Scoones, 1998). Our findings reveal that rural households in the Miombo woodlands can be categorised into three forest use strategy choices with highly varying levels of income (Table 6). The cluster categories are specialised charcoal sellers (32.3%), forest food and charcoal sellers (18.2%), and pure subsistence-orientated forest users who constitute 49.5% of households.

Specialised charcoal sellers, and forest food and charcoal sellers (i.e. charcoal households) earned a higher total forest income (i.e. cash and subsistence forest income) compared to pure subsistence-orientated households. These findings are consistent with Mwitwa and Makano (2012) in Zambia, and Smith et al. (2017) in Malawi which observed that households participate in charcoal to generate income to meet one-off purchases of expensive items. This finding confirms the role of charcoal in meeting the income needs of households (Zorrilla-Miras et al., 2018), but also indicates that charcoal producing households are more affluent than pure subsistence-orientated forest users (Angelsen et al., 2014; Smith et al., 2017). With this logic, pure subsistence-orientated forest users are closely linked to poverty (World Bank, 2018), collecting mainly forest foods (Rowland et al., 2017), poles and fibres (Langat et al., 2016).

Furthermore, our study categorises households based on their use of unprocessed and processed forest products to derive household

Table 8
MNL Results for the Determinants of Households Forest Use Strategy Choices (Pure subsistence-orientated forest users (Cluster 1) as reference).

Variables	Coef. Std. Err.	
	Cluster 2 (Specialised charcoal sellers)	Cluster 3 (Forest food and charcoal sellers)
Natural capital		
Walking distance from household to public forestland (km)	0.344***(0.100)	0.389***(0.114)
Walking distance from household to private forestland (km)	−0.282***(0.107)	−0.341**(0.153)
Human capital		
Size of Household (number of adult equivalent)	−0.120*(0.072)	0.131(0.093)
Age of head of household (years)	0.007(0.009)	−0.026**(0.013)
Social capital		
Household belongs to the largest ethnic group (1-Lamba; 0-otherwise)	0.347(0.250)	0.248(0.317)
Duration of residence in the village (years)	−0.013(0.010)	0.007(0.012)
Financial capital		
Net income from off-farm (Kwacha)	0.000(0.001)	0.001*(0.001)
Physical capital		
Tropical livestock unit (current stock)	−0.027(0.036)	−0.103(0.058)
Land-size per adult equivalent (ha)	−0.031(0.044)	0.029(0.052)
Infrastructure (exogenous)		
Household had access to road usable throughout the year (yes-1, 0-otherwise)	−0.657**(0.271)	−0.760**(0.369)
Village dummy		
Restriction (village is in restricted arrangement-1, 0-otherwise)[a]	0.176(0.289)	1.159***(0.374)
Constant	−0.184(0.548)	−1.425**(0.717)
Number of observations = 412		
LR chi2 (22) = 99.80		
Prob > chi2 = 0.000		
Log likelihood = −371.636		
Pseudo R2 = 0.118		

*** Significant at 0.01, ** significant at 0.05, *significant at 0.1; standard error in parenthesis.
Multicollinearity was checked for by conducting a variance inflation factor (VIF). All the variables had < 10 VIF. However, variables that showed p > .5 in both Clusters 1 and 2 were removed from the model through manual backward stepwise elimination. [a]Dummy for village fixed effect.

subsistence and cash income needs. Categorising households enables policymakers to create policies particular to a target group, which leads to the development of effective, sustainable forest management strategies. Overall, 50.5% of rural households in the study area adopted charcoal strategies, these were specialised charcoal sellers, and forest food and charcoal sellers (Table 6). In the rural Copperbelt province, charcoal strategy choices were the most remunerative relative to subsistence-orientated strategy choice. This outcome is in agreement with other studies that participating in charcoal production can improve the income of rural households in Africa (Khundi et al., 2011; Smith et al., 2017; Zorrilla-Miras et al., 2018).

In terms of per capita production, the volume of charcoal produced and firewood extracted varied according to the restriction regime of the landscape in which the household belonged. Restricted forestlands generated higher per capita volumes of charcoal and firewood than non-restricted forestlands (Table 5); this implies that extraction rather takes place in restricted landscapes rather than in non-restricted landscapes (Tugume et al., 2015), but also suggests that restriction does not affect households' use of forest resources (Jagger et al., 2014). Our finding reveals the potential overlapping claims on forest resources and potential weakness in Zambia's forest policies (Kalaba, 2016; Kalaba et al., 2014). However, in terms of charcoal as a driver of forest degradation (Vinya et al., 2011), our finding is not surprising as other studies observed charcoal production as driving forest degradation in most countries in sub-Saharan Africa, and Zambia in particular (Handavu et al., 2019; Tembo et al., 2015; Zulu and Richardson, 2013). Given that we observed higher volumes in restricted landscapes, restriction, therefore, does not generally affect household reporting of forest products, but our findings imply that restricted landscapes are more intensively used than non-restricted landscapes.

With regard to per capita consumption for charcoal, we found 447.29 kg/year (4.03m^3/year/AEU), and 269.51 kg/year (2.43m^3/year/AEU) in restricted and non-restricted landscapes respectively, which is identical to results observed in rural and urban Kenya 287 kg/year, and 394 kg/year, respectively (Kituyi et al., 2001); and Myanmar (280 kg/year) (Win et al., 2018) respectively. For per capita consumption of firewood, our findings were lower (i.e. 709.93 kg/year (0.23m^3/year/AEU), and 661 kg/year (0.22m^3/year/AEU)) in restricted and non-restricted landscapes respectively, but closer to the results in the previous studies. For example, in Myanmar, the per-household firewood consumption was 780 kgs/year (Win et al., 2018), in Kenya 780 kg/year, and Cambodia 760 kg/year (Top et al., 2003). The lower consumption of firewood in our study compared to the past studies could be attributed to the large household size in our study sites, 5.9 persons/household (4.5 AEU), compared to Kenya 5.5 person/household (Kituyi et al., 2001), and Myanmar 5.1 person/household (Win et al., 2018). Our finding is supported by the previous studies that found per capita consumption rates decrease exponentially with increasing household size, thus implying larger households are more efficient users of fuelwood than small ones (Kituyi et al., 2001).

5.4. Factors determining households' forest use strategy choices

Our analysis reveals the key capitals that influence households' forest use strategy choices in the Copperbelt province of Zambia are; natural, human, and financial (Table 8). Further providing evidence that households pursue different forest use strategies in accordance with the livelihood capitals at their disposition. The differences in household capital lead to differing forest use strategy choices among households, corresponding with Nguyen et al. (2015), and Babulo et al. (2008) who analysed livelihoods in Cambodia and Ethiopia, respectively.

Our study found that people who live closer to the public forestlands and had access to the forests were more likely to be in Cluster One (pure subsistence-orientated forests users). In contrast, we found charcoal producers (Cluster Two and Cluster Three) to be located further from public forestlands but closer to the exclusively owned forestlands, which corresponds with previous studies (Top et al., 2003; Win et al., 2018), indicating that access to woodfuel results in higher consumption rates. While our findings only relate to distances from forestlands, it demonstrates that forests owned exclusively are more susceptible to forest degradation than public forestlands. These findings are notable given that past studies to have often shown that secure tenure rights are linked to sustainable forest use (Andersson et al., 2018; Larson et al., 2010; Shi et al., 2016; Stickler et al., 2017). Thus, in this context, we suggest that assured ownership, particularly in traditional forest areas, does not necessarily solve the challenges of sustainable forest management on its own, in agreement with Lambini and Nguyen (2014), who compared the impact of institutional rights on forest livelihoods in Ghana and Vietnam and observed high levels of unsustainable exploitation in adjacent forest communities. Our findings further confirm that participation in charcoal production is greatest where households are located closer to the roads (Khundi et al., 2011; Mushtaq et al., 2014; Win et al., 2018).

For household capital, despite relatively high population growth in Copperbelt (CSO, 2012), our findings for household size and age of the household head are consistently negative and significant for charcoal households (Clusters Two and Cluster Three) (Fox, 1984; Kituyi et al., 2001; Win et al., 2018). For example, the collection of forest products in rural Copperbelt province is mainly linked to the household ability and cash needs (Handavu et al., 2019; Kalaba et al., 2013a; Tembo et al., 2015). Thus applying this logic, one is inclined to suggest that larger sized households are associated with low income in the rural areas of the Copperbelt because a household with a large membership has a broader option for other livelihood strategies. For the age of the household head, our findings suggest that households with relatively older heads are less likely to participate in the production of charcoal and, if they do, they are still unlikely to specialise in charcoal production (Khundi et al., 2011; Mulenga et al., 2014).

In addition, our findings indicate that off-farm income positively improves the probability of households belonging to the forest food and charcoal seller cluster (Cluster Three). While Cluster Three households are also involved in the production of charcoal, they have a comparatively reduced income when compared to the specialised charcoal sellers (Cluster Two). Yet Cluster Three still have higher incomes than the pure subsistence-orientated forest users, which means that off-farm activity reduces participation in the production of charcoal while subsistence activity rises. These findings are in agreement with (Mulenga et al., 2017; Nguyen et al., 2015), who observed that increasing off-farm activity is likely to reduce participation in charcoal production as rural households are less likely to engage in relatively resource-intensive activities.

Although we found higher forest product extraction in restricted landscapes compared to non-restricted landscapes (Table 5), restriction of forest resource use significantly influenced strategic forest use choices (Table 8). Belonging to a restricted landscape significantly increased the likelihood of households belonging to Cluster Three (only 18.2% of the households) compared to Cluster One (49.5% of the households). These findings indicate that the use of forest products in forested landscapes is culturally intertwined with people's livelihoods (Angelsen et al., 2014; Chidumayo and Gumbo, 2010; Handavu et al., 2019; Mulenga et al., 2014), and restrictions on the use of forest products have little or no effect on domestic extractive patterns (Naughton-Treves et al., 2007; Syampungani et al., 2016).

6. Conclusions and policy implications

Forest products are essential livelihood strategy choices for rural households in forested landscapes. Our study shows that the share of forest income in the province of Copperbelt is 54.1% and higher than any rural income source. In contrast to other studies, the contribution of forests to Zambia's rural households ranged from 22 to 44% (Jumbe et al., 2008; Kalaba et al., 2013a; Mulenga et al., 2014). Such variability in findings shows that the economic importance of forests to Zambia's people is not yet adequately understood, and researchers and policymakers need more effort to gain a better understanding of the forests of Zambia.

Our study also shows that households in the province of Copperbelt of Zambia follow three distinct forest use strategies, which include pure subsistence-orientated forest users, specialised charcoal sellers, and forest food and charcoal sellers. Participation in charcoal production is associated with high income and accounts for about 50.5% of households in our study area; however, only one-third of households in the study area are involved in specialised charcoal production. As a result, we can conclude that charcoal production is a highly remunerative rural livelihood strategy, although with relatively high resource demands.

This study demonstrates that the producers of charcoal lived closer to exclusively owned forestlands than to public forestlands. The findings in this study, however, relate only to distances from forestlands, and they indicate that forestlands owned exclusively are more vulnerable to forest degradation, but we have not yet tested this hypothesis. Careful estimates (Table 5) indicate that most forest pressures are associated with the production of charcoal as the basis of cash income in rural areas. It is important to note that this study focus does not permit conclusions on whether forest use strategies implemented by households have a critical effect on forest losses. Nevertheless, if all households were to adopt the production of charcoal as a source of cash income, Miombo Woodland's productive capacity could be exceeded, eventually leading to unsustainable use that would impact both subsistence and commercial forest users.

Considering that rural households in the Copperbelt province adopted three strategic forest use choices, with varying income levels, we propose that characterising households based on forest product use is critical to understanding local livelihoods, providing a more nuanced perspective of the linkages between people and forest landscapes. In this regard, we suggest that policymakers and conservationists adopt approaches that consider the subsistence and charcoal needs of households. This can be achieved by introducing coppicing or reforestation systems that are consistent with the growing demands of Miombo, promoting sustainable forest product extraction, including charcoal production. Otherwise, overharvesting by charcoal producers' could further threaten subsistence-orientated household's livelihoods. Future studies should focus on understanding macro-level factors that drive forest loss, but not lose sight of the micro-level features and the choices made by individual households.

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Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Appendix A

Table A1
Definition of the Independent Variables used in the Regression Models.

Variable	Definition	Unit	Literature
Natural capital			
Distance to forestland (-public)	Distance from household to the public forestland	km	Nguyen et al. (2015); Ali and Rahut (2018); Tugume et al. (2015)
Distance to forestland (-exclusively-owned)	The distance that household walk to exclusively-owned land	km	Khundi et al. (2011); Dash et al. (2016)
Forest-cover loss	Households report to have observed forest-cover loss over the last five years in the village (dummy 1 = yes/0 = no)	1/0	
Human capital			
Age	Age of head of the household	Years	Ali and Rahut (2018); Angelsen et al. (2014)
Gender	Male-headed household (dummy 1 = male/0 = female)	1/0	Pouliot and Treue (2013); Sunderland et al. (2014)
Household-size*	Household-size, adult equivalent	AEU	Ali and Rahut (2018); Angelsen et al. (2014); Dehghani Pour et al. (2018)
Education	Head of household attained high-school level and higher levels (dummy 1 = high school and higher levels /0 = otherwise)	1/0	Kamanga et al. (2009); Nakakaawa et al. (2015)
Social capital			
Ethnicity	Household belongs to a major ethnic group, (1 = Lamba, 0 = other tribes)	1/0	Adhikari et al. (2004); Kar and Jacobson (2012); (Torres et al., 2018)
Mobile phones	Number of mobile phones	number	Hartje and Hübler (2015); Nguyen et al. (2015)
Duration of residence	Years household lived in the village	years	Jumbe and Angelsen (2007)
Financial capital			
Access to credit	Household members had access to credit in the last 12 months (dummy 1 = yes/0 = otherwise)	1/0	Torres et al. (2018); Barrett et al. (2001)
Crop income**	Household-earned from crop	Kwacha/AEU	Kamanga et al. (2009); Mulenga et al. (2017)

(continued on next page)

Table A1 (*continued*)

Variable	Definition	Unit	Literature
Off-farm income	Household-earned income from off-farm	Kwacha/AEU	Mulenga et al. (2017)
Self-employment	Household-earned income from self-employment	Kwacha/AEU	
Total remittances***	Household-earned income from remittances	Kwacha/AEU	Nguyen et al. (2015)
Wages	Household-earned wages	Kwacha/AEU	
Physical capital			
Livestock	Tropical livestock unit (TLU)-(stock)	number	Soltani et al. (2012)
Land owned	Land owned by household per AEU	Ha/AEU	Torres et al. (2018); Ali and Rahut (2018); Mulenga et al. (2017); Stickler et al. (2017); Andersson et al. (2018); Larson et al. (2010); Shi et al. (2016)
Infrastructure (exogenous)			
Access to the road network	Household reports to have at least access to a road useable by car throughout the year (paved or gravel) (dummy 1 = paved/0 = otherwise)	1/0	Jansen et al. (2006); Soltani et al. (2012); Babulo et al. (2008)
Distance to the main road	Distance to the main road	km	Babigumira et al. (2014)
Vulnerability context (exogenous)			
Income shock -Crop failure	Household reports having experienced serious crop failure in the past 12 months (dummy 1 = yes/0 = otherwise)	1/0	Angelsen et al. (2014); Babigumira et al. (2014)
Asset shock -Livestock loss	Household reports having experienced serious livestock loss in the past 12 months (dummy 1 = yes/0 = otherwise)	1/0	
Labour shock -Serious Illness/death of a family member	Household reports having experienced illness of family member in the past 12 months (dummy 1 = yes/0 = otherwise)	1/0	

*Adult equivalent (AEU) as applied by Dokken and Angelsen (2015) where adults aged between 15 and 64 are assigned a weight of one (1), and dependents below 15 and above 64 are assigned a weight of 0.5. ** Income is measured in Zambian Kwacha (ZMW). *** Remittances include monetary transfers from government, community support or household members working in another location (internal or abroad).

A.1. *Determining the optimal K-means for cluster*

We performed k-means cluster algorithm using R Version 3.5.3., on data collected from the household survey conducted between 2017 and 2018 in Zambia. To determine the optimal number of clusters for our cluster analysis, we followed procedures as prescribed by Makles (2012). We compared several k-means with a different number of groups. The optimal k-means was three clusters which we zeroed at after observing the kink in Fig. A1.

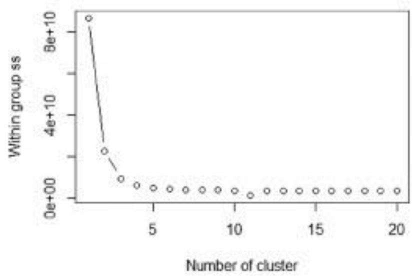

Fig. A1. The scree plot shows the kink for optimal k-means clustering.

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10.2. Publication 2

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Methodological and Ideological Options

Effects of household-level attributes and agricultural land-use on deforestation patterns along a forest transition gradient in the Miombo landscapes, Zambia

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ABSTRACT

Dry forests in tropical and subtropical areas continue to experience high deforestation rates that affect households' dependence on forest resources. Little remains understood about the relationship between household factors and deforestation patterns in Zambia. We integrate remotely sensed data with surveys of 1123 households collected in the Miombo areas between 2017 and 2019 to better understand the effects of household attributes on regional deforestation patterns along a forest transition gradient.

We found, in early-to-mid-transition, deforestation patterns systematically decreased further from settlements (homesteads), but this was reversed in regions with advanced forest transition. The socio-demographic attributes, land and non-land-based attributes, and location factors differently affected deforestation across provinces. Although agricultural land-use was significantly associated with deforestation, no distinct patterns emerged across distance categories or along the forest transition. Furthermore, increases in non-farm income reduced the likelihood of high deforestation, but the impact was not always significant across provinces.

Our results indicate that economic effects of distance in Miombo areas complement the forest transition, but are not exclusively related to crop productivity. We assume that different aspects of livelihoods can explain the deforestation patterns in the Miombo areas. Thus, forest management should be regional-specific, such as improving access to financial incentives in North-Western, and reforestation and agroforestry in Copperbelt and the Eastern Province.

1. Introduction

Dry forests account for approximately 42% of the global tropical and subtropical forests (Murphy and Lugo, 1986). These forests are important because they incorporate woodland management and provide a livelihood base for many people who depend on forest goods and ecosystem services supporting agricultural production (Blackie et al., 2014; McNicol et al., 2018; Pritchard et al., 2019). However, high deforestation rates continue to be reported in most tropical and subtropical countries, particularly in areas where dry forests are dominant (Hansen et al., 2013; Miles et al., 2006). As such, it is understood that there are significant variations in the quantities of forest goods and agricultural products across many countries or regions (Angelsen et al., 2014; Phiri et al., 2019b; Twongyirwe et al., 2018). This has far-reaching consequences on about 800 million people that depend on forest resources and agriculture for a livelihood (Chomitz et al., 2007).

In tropical and subtropical areas, agricultural land uses such as crop production, forest products extraction, and livestock grazing are recognised to influence cropland and pasture expansion (Akinyemi, 2017; Barbier, 2004). For example, Gibbs et al. (2010) observed that between the years 1980 and 2000, about 55% of new agricultural land uses emerged at the expense of forests. Besides, it is understood that rural

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agricultural land uses significantly vary and depends on the distances from population centres (settlements), markets, and crop productivity (returns per unit of land). Thus, variation in distance to agricultural fields can influence agricultural land uses and affect deforestation patterns along forest transition (Angelsen, 2007; von Thünen, 1826). Hence, examining the relationship between household-level attributes, distribution of agricultural land-use, and deforestation is important in understanding the current and expected deforestation for better land-use planning (Mertens et al., 2000). At the same time, understanding factors that underlie deforestation is crucial for reconciling conservation policies and rural development in the forest regions and at the edge of human settlement (forest frontiers) (Schielein and Börner, 2018).

While the previous studies have broadly documented causes of deforestation (De Espindola et al., 2012; Geist and Lambin, 2002; Hosonuma et al., 2012; Rudel, 2013), little is known about the relationship between household attributes, the spatial distribution of agricultural land-use, and deforestation across different landscapes and regions. In part, past studies were constrained by the difficulty of accessing some areas, which affected the generation of adequate survey data (Grainger, 1999). Most studies, therefore, relied on aggregated and large-scale data (Babigumira et al., 2014; Hosonuma et al., 2012; Köthke et al., 2013; Rudel, 2013), case studies or only remotely sensed data (Bone et al., 2017; Ryan et al., 2014) to estimate and analyse causes of deforestation. Yet, in tropical and subtropical areas, landscapes and regions typically display contrasting household-level attributes (Twongyirwe et al., 2018; VanWey et al., 2007) and variations in agricultural land-use (De Espindola et al., 2012; Gibbs et al., 2010), which can affect the trajectory of deforestation in different ways (Etter et al., 2006; McNicol et al., 2018).

Zambia, for example, with about half of rural household income derived from agriculture (Tembo and Sitko, 2013) and more than 20% from forest products (Jumbe et al., 2008; Mulenga et al., 2014), shows a significant contrast between household characteristics and the spatial distribution of agricultural land-use across provinces (Shakacite et al., 2016; Tembo and Sitko, 2013). The spatial distribution of agricultural land-use among households stems in part from policies that provide unequal access to land (Sitko and Jayne, 2014) and crop subsidies (Mason et al., 2013) that affect crop types grown across landscapes and provinces (regions). Therefore, we expect regional variations in the relationships between household-level attributes, the spatial distribution of agricultural land-use and deforestation patterns.

A few studies in Zambia have attempted to estimate (FAO, 2015; Phiri et al., 2019a) and examine causes of deforestation at national and subnational levels (Phiri et al., 2019b; Vinya et al., 2011), but the estimates vary substantially. Kamelarczyk and Smith-Hall (2014) reported that studies in Zambia in recent decades have neither accurately estimated deforestation nor adequately documented the causes of deforestation. Moreover, we have not found any study empirically examining the relationship between household-level attributes, the spatial distribution of agricultural land-use, and deforestation. The spatial effects of households' land use can be attributed to shifts in agriculture, which can be in proximity to the settlements (Chidumayo, 1987b). However, as population pressure increases and land becomes unsuitable for crop production, new croplands are being expanded, leading to higher deforestation in more remote areas (areas further away from settlements) (Grogan et al., 2013; Phiri et al., 2019b).

Additionally, given that rural households are not independent of community-level or neighbouring land-use decisions (Adams, 2003), land-use can also be affected by external factors, resulting in a complex spatial distribution of agricultural land-use and deforestation outcomes. Hence, in this study, household characteristics are systematically assessed as socio-demographic attributes, land-based attributes, non-farm income, and location factors such as access to major roads (Babigumira et al., 2014).

The problem addressed in this paper is based on the economic theory of land allocation, which suggests that optimal returns (maximum returns on a unit of land) affect the spatial distribution of agricultural land-use (von Thünen, 1826). Although von Thünen (1826) theory focuses primarily on the effects of transport costs on physical production, it shows in particular how agricultural returns affect the spatial distribution of land use (see Peet (1969); Peet (1970) for the interpretation of von Thünen theory). This model yields several critical insights on the immediate cause of deforestation. However, when considering a model where land has only two uses (Angelsen, 2007): forest and agriculture, higher output prices and technological innovations increase crop yield or reduce input costs, making land-use expansion more attractive. Accordingly, reduced access costs such as new or better roads provide a great stimulus for deforestation (Barber et al., 2014), while higher wages work in the opposite direction (Verburg et al., 2006). In their study that reviewed about 140 economic models of deforestation, Angelsen and Kaimowitz (1999) find a broad consensus on three immediate causes of deforestation: higher agricultural productivity, proximity to processing areas (mostly households), and shortage of off-farm employment. We transfer this concept to rural households across the different forest regions of the Miombo woodlands to examine, among other things, how crop productivity influences the spatial distribution of land use, thus affecting deforestation along the forest transition.

Against this backdrop, we relate household survey data to remotely sensed deforestation data (Hansen et al., 2013) to examine how household-level attributes and the spatial distribution of agricultural land-use affect deforestation along the forest transition gradient in Zambia. We asked the following specific questions: 1. What are the patterns of deforestation across distance categories and forest transition context in the Miombo forest landscapes? 2. What household-level attributes affect deforestation along a forest transition gradient in the Miombo forest landscapes? 3. How does the spatial distribution of agricultural land-use (i.e., subsistence and commercial crop) affect deforestation along a forest transition gradient in the Miombo forest landscapes?

Thus, the rest of this paper is organised as follows: Section 2 briefly describes forest transition and the conceptual framework (von Thünen approach). Section 3 describes the methods, data and analytical approach. The empirical results are presented in Section 4, discussion in Section 5, and the conclusions are given in Section 6.

2. Forest transition and the conceptual framework

2.1. *Historical features of forest transition along the Miombo forest landscapes of Zambia*

Forest transition concerns long-term changes in the extent of forest cover in a country or region (Mather, 1992). As such, it describes patterns of forest cover changes across regions, including high forest cover and low deforestation (stage 1), followed by accelerating and high deforestation (stage 2), and decline in deforestation and reforestation (stage 3) (Mather and Needle, 1998; Rudel et al., 2005). It is suggested that during the early forest transition, households rapidly clear land leading to a decline of forest cover. Later, as rural development and urbanization spread, social and economic processes such as rural-urban migration shift. This results in the abandonment of farmlands, which leads to reforestation (Wolfersberger et al., 2015).

Until recently, there has been increased concern about deforestation and forest degradation in tropical dry forest areas (FAO, 2015; McNicol et al., 2018; Poker and MacDicken, 2016); however, the designs of most studies examining forest cover trends make examining agricultural land-use and forest transition difficult. Typically, most studies rely on case studies to analyse forest cover changes, and when longitudinal data are used, the time series are often limited (Gibbs et al., 2010; Phiri et al., 2019a; Twongyirwe et al., 2015). Moreover, there are diverse climatic, ecological and biophysical, and socio-economic conditions in the tropical and subtropical areas, suggesting multiple pathways to the forest transition (Meyfroidt, 2013; Phiri et al., 2019b; Singh et al., 2017).

Despite interests in describing the processes of forest cover changes (Köthke et al., 2013; Rudel et al., 2005; Singh et al., 2017), there has not been any detailed empirical assessment of how agricultural land-use changes along a forest transition gradient.

This study uses historical data on forest cover from 2000 (Hansen et al., 2013) to assess the forest transition concept and agricultural land-use across the Miombo forest gradient in the North-Western Province, the Copperbelt and the Eastern Province of Zambia (Table S1). The North-Western Province measuring an area of approximately 124,233.90 km^2, has a population of about 727,044 people, with a mean population density of 5.8 persons per km^2 (CSO, 2012). This province receives an annual rainfall ranging from 1000 to 1500 mm, reflecting the wet Miombo (Chidumayo, 1987a; Chidumayo, 2019) and has about 74.5% of its total land area covered by forests (Hansen et al., 2013). Different ethnicities inhabit the North-Western Province; however, the largest ethnic group include the Lunda and the Kaonde (CSO, 2012). The loss of forest cover in the North-Western Province has been attributed primarily to logging and expanding mining industries (Gumbo et al., 2013; Vinya et al., 2011).

The Copperbelt Province covers an area measuring 31,401.90 km^2, with a population of approximately 2 million people, has a population density of about 63.0 persons per km^2 (CSO, 2012). Forest cover in this province is estimated at 64.4% of the total land area (Hansen et al., 2013) (Table S1). The province receives rainfall higher than 1000 mm, reflecting the wet Miombo vegetation (Chidumayo, 2019). The Copperbelt is the second urbanised province in Zambia and consists of multicultural tribes, with the Lamba being the dominant group (CSO, 2012). The establishment of the mines industry in the 1920s and the subsequent expansion from 1950 to 1970 is considered a significant factor leading to the Copperbelt Province's economic transformation (Mususa, 2012). As such, the Copperbelt remains the second-largest urbanised province in Zambia (CSO, 2012). As a result, the demand for food and cheap fuelwood is higher in the Copperbelt Province than in the North-Western and the Eastern Province (Tembo et al., 2015; Zulu and Richardson, 2013), thereby accelerating deforestation (Vinya et al., 2011).

The Eastern Province covers an area measuring 50,544.90 km^2, has a population of about 1.6 million people, of which the majority reside in the rural areas. This province has a population density of 30.9 persons per km^2 (CSO, 2012). The Eastern Province has about 17.5% of its total land area covered by forests (Table S1) and receives an annual rainfall of less than 1000 mm, reflecting the dry Miombo (Chidumayo, 1987a; Chidumayo, 2019). In recent decades, the emphasis on agricultural production in the Eastern Province (Tembo and Sitko, 2013) has substantially decreased forest cover (Global Forest Watch, 2020; Hansen et al., 2013). Maize is the dominant subsistence crop grown in this province but also grown in other provinces (Tembo and Sitko, 2013). On the other hand, various crops contribute to household commercial needs (cash income), with groundnuts, beans, soybeans, sunflower and vegetables as the major cash crops (Gumbo et al., 2016; Ngoma et al., 2019; Tembo and Sitko, 2013).

Hence, the long-term forest cover changes (Table S1) and patterns of forest transition in our study provinces appear to be driven by anthropogenic factors such as cropland expansion, forest products extraction and changes in households' socio-demographic characteristics (Chirwa et al., 2008; Dewees et al., 2010; Phiri et al., 2019b; Vinya et al., 2011).

2.2. Conceptual framework

By applying the land allocation theory (von Thünen, 1826) and the forest transition concept (Rudel et al., 2005), past studies suggest that the spatial distribution of agricultural land-use can differently influence deforestation patterns along the forest transition (Angelsen, 2007; Schielein and Börner, 2018) (Fig. 1). This indicates that crop returns (net income) per hectare in a year (i.e., referred to crop productivity) can determine land use, which varies across distance categories from settlements (von Thünen, 1826). Crop productivity was calculated as income (i.e., Zambian Kwacha) for each crop type per hectare per year (crop income ha^{-1} yr^{-1}). In Zambia, for example, the expected returns from crop production have been recognised to differently affect the spatial distribution of cropland allocation to different crops, which varies across provinces (Chapoto et al., 2006; Tembo and Sitko, 2013).

Hence, agricultural production for subsistence purposes will depend on costs related to distances from land-use patches (plot) to households' homesteads. Commercial crop production, requiring processing, in turn, will depend on cost structures from land-use patches to the place of processing (mostly households) and the distance from the household to the road (Angelsen, 1999; Freitas et al., 2010). As such, land productivity, historical deforestation, subsistence and commercial crop production can influence spatio-temporal patterns of land-use and deforestation along the forest transition (Fig. 1).

Incorporating distances and integrating crop income (crop productivity) into the forest transition, therefore, can provide a means to examine the effects of the spatial distribution of agricultural land-use

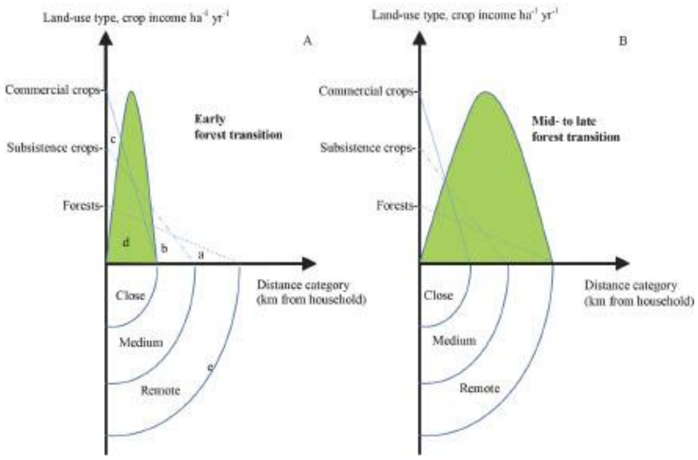

Fig. 1. Relative distribution of land-use and major crop types, and deforestation across distance categories at varying forest cover. Fig. 1A: early forest transitions (stage 1) and Fig. 1B: mid- to-late forest transition (stage 2 and 3). Area (a) is a remote distance category that describes marginal areas with forest prevalence. Area (b) is medium-distance category that represents extensive production. Area (c) is close-distance category that represents intensive production. Area (d) is the expected forest loss area, and area (e) is concentric rings representing areas of land-use. *Source:* adapted from Angelsen (2007) and Schielein and Börner (2018).

(Angelsen, 2007; Barbier, 2004) and deforestation patterns along the forest transition phases (Angelsen, 2007; Schielein and Börner, 2018). In the early forest transition phase (stage 1), commercial crop production (high return crops) is expected to be associated with high deforestation rates at close-distance categories (areas closer to settlements). Simultaneously, subsistence crop production is expected to be associated with low deforestation further from households (remote-distance categories) (Fig. 1). These sequences of land-use and deforestation patterns are as well expected in mid-to-late forest transition phases (stage 2 and 3). However, since deforestation accumulates over time, high deforestation is expected both at close-distance and remote-distance categories in stage 2 and 3, respectively (Schielein and Börner, 2018). We seek to test

Fig. 2. Map of Zambia showing study landscapes and computed spatial units representing areas of household influence and deforestation. The average distances walked by households from their homesteads to agricultural land-use patches were calculated and used to define the boundaries of the distance categories (rings) in each study landscapes.

this hypothesis.

Distance categories in this study were calculated following the method shown in Table S2. Approximately 25% of households had land-use patches at the close-distance category, 50% medium-distance category, and the last 25% of households had land-use patches at the remote distances.

3. Material and methods

3.1. Study site selection

The study sites were selected in the three study provinces of the North-Western, Copperbelt and the Eastern Province (Fig. 2). For each region, we reviewed available literature in order to understand the socio-economic characteristics of its inhabitants and forest cover trends from the year 2000 to 2018 (Hansen et al., 2013; Shakacite et al., 2016). We also conducted a scoping study that led to the selection of landscapes in six districts throughout the study provinces (Table S1).

In each study district, we consulted government officials, chiefs and sub-chiefs (*Indunas*) that enabled us to classify the landscapes in terms of forest management regimes. This resulted in selecting paired landscapes with different restriction regimes but similar forest cover areas, livelihoods and forest resources. While a forest reserve partially covered one of the paired landscapes in each case (Kazungu et al., 2020; Nansikombi et al., 2020), the other had no restriction in terms of access to and use of forests (i.e., open-access) (Table S1).

Overall, we selected six pairs of landscapes distributed in *Mufumbwe* and *Mwinilunga* in the North-Western Province; *Lufwanyama* and *Masaiti* in the Copperbelt Province; and *Petauke* and *Nyimba* district in the Eastern Province. Thus, the selected landscapes reflect declining forest cover along the forest transition, with the highest forest cover in the North-Western and the lowest in the Eastern Province (Table S1 and Fig. 2).

3.2. Data collection

3.2.1. Household surveys

We conducted household surveys between 2017 and 2019 in twelve (12) forest landscapes located in our study area (i.e., North-Western, Copperbelt, and Eastern Province). In each landscape, a structured questionnaire was administered to approximately 100 households, resulting in 1200 surveys. The questionnaire captured information about household socio-demographics, sources of income from land (i.e., agriculture, livestock, forest use), non-farm activities (i.e., salaries, remittances, self-employment), off-farm activities (i.e., working in other people's farm), changes in land-use (Table S3), and agricultural land-use patches. The participating households were selected according to the methodology defined by Kazungu et al. (2020). In this study, however, 1123 households were included in the final sample after removing implausible surveys and missing values (Fig. 3).

Furthermore, to collect market information on agriculture and forest products, we identified local markets for each village in the study area. This was done following the procedures described by Angelsen (2011). Accordingly, this study assumes that every household has access to the market. Based on the information on quantities of products collected, consumed and sold, production costs and prices reported, we calculated net income values for household livelihood activities (see also Kazungu et al., 2020). This study's crop or forest income implies the total net value of subsistence and cash income attained by a household in a year, which is in Zambian kwacha (ZMW). At the time of data collection, 1 USD was equivalent to 10.13 ZMW (Bank of Zambia, 2018). Subsistence incomes were calculated using the prices reported for each activity, such as crop or forest products. Regarding the missing prices, which occurred when households did not sell any part of the product, this was calculated using the average village price as a proxy for that commodity.

To understand land-use patterns, we estimate crop productivity (Tembo and Sitko, 2013). Crop productivity is expressed as crop returns (net income) per hectare per year (income ha^{-1} yr^{-1}). Thus, crop productivity can influence land distribution and is considered a valuable way of determining the different crop types' relative attractiveness. Therefore, common crop types were grouped to enable the calculation of

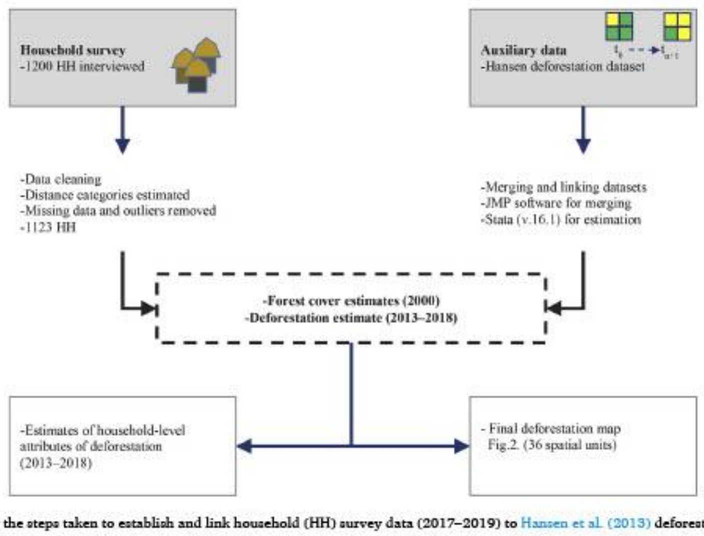

Fig. 3. Flowchart showing the steps taken to establish and link household (HH) survey data (2017–2019) to Hansen et al. (2013) deforestation dataset (2013–2018). The rectangle shape with broken lines represents the process taken to ensure the usability of the dataset, while bold shapes with blue fill show sources of data and final output. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

crop productivity during the study period. The groups include cereals (mainly maize), legumes (mostly beans and groundnuts) and vegetable (all forms of vegetable).

3.2.2. Calculating distance categories in the study area

In computing the distance categories, we considered walking distances from homesteads to agricultural land-use patches reported by households during the survey (Kazungu et al., 2020). Since households had more than one patch of land under use, and because these patches were located at different distances from the homesteads, each household's average distance walked from a homestead to agricultural land-use patches was estimated.

To aggregate household distances at the landscape level, three distance categories (rings), close, medium, and remote were defined (Table S2). We applied thresholds (Q25 - Q75 of average walking distances) in order to categorise distances into three groups in each of the 12 landscapes. All distances below the quantile 25% (Q25) were grouped into the close-distance category. The distances above the 75% quantile (Q75) were classified as remote- distance category (Table S2), whereas distances between the 25% and 75% quantiles were classified as medium-distance category (Table S2).

The distance categories provided the basis for establishing thirty-six (36) spatial units (three distance rings in 12 landscapes) representing the areas of households' influence on deforestation (Fig. 2). The landscapes' average size was 347.5 km^2; most of the landscapes ranged from 92.6 to 567.7 km^2 (Table S1). Within the landscapes, the size of close-distance spatial units ranges from 19.7 to 197.8 km^2, medium-distance rings from 21.2 to 223.2 km^2, and remote-distance rings from 19.2 to 319.6 km^2 (Fig. 2). Additionally, in *Shibuchinga* and *Lumpuma* landscapes, private large commercial farms and tree plantation areas were excluded from distance categories computation. This is because commercial farms and plantations were not accessed by households (see large reddish regions of Fig. 2).

3.2.3. Tree cover and deforestation

This subsection describes the process taken to estimate deforestation in the study sites. We also explain how we linked the households dataset (see 3.2.1) with Hansen et al. (2013) global dataset on forest loss (Fig. 3). Forest cover and forest loss data were generated using Hansen et al. (2013) data (Table S1). This dataset presents tree cover loss as the removal of tree cover, which can be due to fire, mechanical harvesting, disease or the presence of storms. However, the authors are aware that the ecological conditions (e.g., dry vs humid forests) can play an important role in determining canopy density and tree cover thresholds that apply to the specific forest definitions. Tree cover (the density of the tree canopy that covers the surface of the land) is characterised by trees that can be in the form of natural forests or plantations. Therefore, changes in forest cover can be affected by ecological aspects that influence comparisons between different regions.

After visual interpretation of satellite images and comparing these with the ground-truthing findings in the study landscapes, we defined forests as areas with a minimum tree cover of 30% (TC 30%). Deforestation is defined as a loss of tree cover (above 30% threshold) from 2013 to 2018, compared to the reference pixel in 2000 (Hansen et al., 2013). In estimating deforestation, the study considered the period of 2013–2018 as this timeframe is close to the 2017–2019 period in which we collected household data. Deforestation values are calculated for the thirty-six (36) spatial units generated from the distance categories described in subsection 3.2.2. The spatial units represent households' area of influence (Fig. 2), which can occur through crop cultivation or forest product extraction (Rudel, 2013). The deforestation values for 36 spatial units are used to determine deforestation levels, which is the dependent variable used in the analysis (see section 3.3.).

3.3. Data analysis

3.3.1. Estimation of the household-level attributes associated with deforestation

The computed deforestation rates for 36 spatial units mentioned in the previous section were transformed into an ordinal categorical variable to overcome the issue with the distribution of the dependent variable that would have occurred had we considered it a continuous variable. In order to do that, the 36 deforestation rates were grouped as low deforestation level, medium deforestation level, and high deforestation level. The categorization of deforestation rates into three levels was done using the "xtile" command in STATA version 15.1. The impact of household-level attributes on deforestation levels was analysed using the generalised ordered logistic (gologit) regression model. The generalised version of the ordered logit model was chosen because it allows imposing the proportional odds assumption on all the variables that do not meet this assumption (Williams, 2006). The proportional odds assumption or parallel line (pl) assumption states that the relationship between each pair of outcome groups (deforestation levels) is the same (Fullerton, 2009). As such, there is only one set of coefficients, i.e., one model for each region.

In the generalised ordered logistic regression model, the dependent variable is an ordinal variable Y, which in this study takes the values 1 = low deforestation, 2 = medium, and 3 = high deforestation. The gologit regression model takes the form (Williams, 2006):

$$P(Y_i > j) = \frac{exp(\alpha_j + X_i\beta_j)}{1 + [exp(\alpha_j + X_i\beta_j)]}, j = 1, 2, ..., M - 1$$

where P is the probability, j is the deforestation level (Low, Medium, & High), α_j is a parameter that represents the thresholds or cut points (Grilli and Rampichini, 2021), β_j is a vector of the parameters to be estimated (coefficients). X_i is a vector for explanatory variables for household i. This includes age of household head, gender, education level, household size, residence duration, ethnicity, land size, livestock, incomes (forest, crops, fish capture, off-farm and non-farm), distances to forests and markets, landscape dummy and interactions (i.e., crop productivity and distance categories). And M is the number of categories of the ordinal dependent variable.

Furthermore, since the coefficients for parameters β_j cannot be directly interpreted, we estimate the marginal effects. The marginal effects indicate the change in the probability of observing a specific outcome of Y when an explanatory variable increases by one unit for continuous variables or a discrete change from 0 to 1 for dummy variables. A significant positive coefficient means that higher values of the independent variable make the dependent variable more likely. The parameters are estimated using the maximum likelihood estimation method.

We generate generalised ordered logistic regression results for the provinces and the whole sample, reflecting the spatial extent of the analysis. The province-specific analysis forms the core thesis of our discussion. Before gologit regression analysis was done, statistical diagnostics were done, including checking for the pseudoreplication (Hurlbert, 1984) and collinearity between explanatory variables. Following the procedures described by Ramage et al. (2013), we conducted a one-way ANOVA to compare the relationship between deforestation strata and distances within each treatment to the relationship between deforestation and distances across treatments. The within-treatment and across-treatment were significant for all regions (Table S4). This indicates that there are important differences in the deforestation strata in each region. As such, there is a substantial justification to infer a treatment effect in our study.

Additionally, all the selected variables were below the accepted level of 0.7 correlation coefficient (Dormann et al., 2013). Moreover, we standardized all continuous explanatory variables by dividing the values by their respective standard deviations. This was done because households across the provinces exhibited substantial variation in their socio-demographic characteristics, income and location attributes. Standardising explanatory variables was done to allow comparisons of the relative effect of each variable across provinces (Schielzeth, 2010). Standardizing was achieved using the egen command in STATA. However, factor variables that included gender of the household head, ethnicity, road access, distance categories and restriction regimes are not standardized because they have distinct provincial imbalances, and this could alter weighting.

4. Results

4.1. Characteristics of households in the study area

Overall, 82% of households in our study area were male-headed, consisting of six members, and had lived in these areas for about 16 years. In addition, households own land patches measuring 3.3 ha, and most live about an hour away from the main road. The North-Western Province had the largest share of households (51.3%) accessing permanent roads compared to an average of 43.7% (Table 1). However, most household characteristics do not vary widely across provinces (Table 1).

The North-Western Province has about 62% of the households belonging to the Lunda ethnic group (Table 1). The household size in this province is slightly larger (6.5 members), and better educated than the households in the Copperbelt and the Eastern Province (i.e., about 29% of households attained above primary education levels in the North-Western Province compared to Copperbelt (25%) and the Eastern Province (17%)) (Table 1). Besides, households in the North-Western Province stayed closer to village centres. They had the highest (51%) proportion of households accessing permanent roads compared to both the Copperbelt (32.7%) and the Eastern Province (47.9%) (Table 1). On the other hand, the Copperbelt Province had the largest average land size per household (4.7 ha), tropical livestock units (1.4) and a total annual income of 13,528.7 ZMW per household compared to both the North-Western and Eastern Province (Table 1). In the Copperbelt Province, approximately half of the households belong to the Lamba ethnic group. In comparison, about 96% of households reported belonging to the Nsenga ethnic group in the Eastern Province (Table 1).

4.2. Household income across study provinces and distance categories

We show households' income sources across provinces and distance categories in Table 2A and B. In the North-Western Province, income from crop production contributed to 52% of total household income, while income from forests (unprocessed products and charcoal production) made up 33.6% (Table 2A). In the Copperbelt Province, income from forests contributed to the highest proportion, accounting for 65% of total household income compared to crop production (23%) (Table 2A). Similarly, forest income in the Eastern Province had a higher relative contribution to total household income than crop production (Table 2A). Notably, the total income from crop production decreased from North-Western over Copperbelt to Eastern Province. In general, we could not depict other variables' trends, but forest production is much more important for households in Copperbelt than in other regions.

In terms of income source distribution across distance categories, we found that forest income is highest in the close- and remote-distance categories, 54.6% and 51%, respectively. Conversely, crop production is highest in the medium-distance (37.3%) (Table 2B). Besides, we note an increasing trend in crop income across distance categories. On the other hand, other income sources vary only slightly across distance categories (Table 2B).

Overall, our results show that there is a pattern of declining crop incomes along the forest transition. At the same time, we observed a trend of increasing crop income across distance categories. Crop and forest income (non-processed products and charcoal income)

Table 1
Characteristics of households across study provinces.

Variables	Provinces			Whole sample (n = 1123)
	North-Western (n = 374)	Copperbelt (n = 394)	Eastern (n = 355)	
	Mean (SD)[a]	Mean (SD)	Mean (SD)	Mean (SD)
Socio-demographic attributes				
Male-headed household, 1 = Yes; 0 = No	81.3%	88.8%	75.5%	82.1%
Head of household attained above primary education, 1 = Yes; 0 = No	29.4%	24.6%	17.2%	23.9%
Age of household head, years	43.7 (15.0)	45.0 (13.9)	46.2 (14.9)	44.9 (14.6)
Household size, number of members	6.5 (2.5)	5.9 (2.5)	5.8 (2.3)	6.0 (2.5)
Household size, adult equivalent units (AEU)	4.9 (2.0)	4.5 (1.9)	4.6 (1.9)	4.7 (1.9)
Duration of residence, years	14.9 (12.0)	16.0 (13.6)	18.0 (18.2)	16.3 (14.8)
Ethnicity, North-Western-Lunda; Copperbelt, Lamba; Eastern, Nsenga	62.0%	49.2%	96.3%	NA
Land and non-land-based attributes				
Total size of the patch of land-use, ha	3.0 (3.5)	4.7 (8.4)	2.0 (1.6)	3.3 (5.5)
Livestock, tropical livestock unit (TLU)	0.5 (1.2)	1.4 (2.4)	1.1 (1.7)	1.0 (1.8)
Total household income, Zambian kwacha (ZMW)[b]	9253.4 (6579.7)	13,528.7 (13,841.2)	5913.8 (3653.8)	9697.7 (9770.2)
Location attributes				
Household distance to the village centre, walking time (minutes)	26.1 (28.0)	61.3 (68.2)	40.6 (49.4)	43.0 (53.6)
Household distance to the main road, walking time (minutes)	89.6 (153.3)	62.2 (74.9)	10.5 (22.7)	55.0 (104.8)
Household had access to permanent road, 1 = Yes; 0 = No	51.3%	32.7%	47.9%	43.7%
Landscape has forest reserve; 1 = Yes, 0 = No	47.3%	49.0%	52.1%	49.4%
Landscape in wet miombo; 1 = Yes, 0 = No	NA	NA	NA	68.4%
Patches of land-use in the close-distance category, per cent of households	8.9%	11.0%	8.0%	28.0%
Patches of land-use in the medium-distance category, per cent of households	18.8%	17.2%	18.5%	54.5%
Patches of land-use in the remote-distance category, per cent of households	5.6%	6.9%	5.1%	17.5%

[a] Standard deviation (SD) in parentheses.

[b] Income is calculated as net incomes in Zambian Kwacha (ZMW) (i.e., revenue minus the cost of production); at the time of data collection, 1USD = 10.13 ZMW (Bank of Zambia, 2018).

Table 2
A. Distribution of household income across study provinces.

Households' sources of income[a]	Provinces						Whole sample (n = 1123)	
	North-Western (n = 374)		Copperbelt (394)		Eastern (355)			
	Mean (SD)[b]	Share of Sample (%)	Mean (SD)	Share of Sample (%)	Mean (SD)	Share of Sample (%)	Mean (SD)	Share of Sample (%)
Land-based attributes								
Forest products (unprocessed), ZMW	2429.0 (2378.7)	26.2	3443.0 (3423.5)	25.4	1941.8 (1578.1)	32.8	2630.7 (2677.2)	27.1
Charcoal production, ZMW	687.7 (1662.7)	7.4	5358.4 (10,445.2)	39.6	363.7 (980.1)	6.2	2224.0 (6690.9)	22.9
Crop production, ZMW	4809.9 (4677.4)	52.0	3168.5 (4353.9)	23.4	2127.2 (2101.9)	36.0	3385.9 (4062.9)	34.9
Livestock production, ZMW	608.2 (1256.8)	6.6	1046.8 (1721.7)	7.7	836.0 (1617.3)	14.1	834.1 (1556.1)	8.6
Capture fish, ZMW	75.6 (167.4)	0.8	30.9 (79.5)	0.2	3.5 (44.5)	0.1	37.2 (114.1)	0.4
Off-farm activities, ZMW	245.9 (459.2)	2.7	106.4 (319.9)	0.8	291.9 (467.3)	4.9	211.5 (425.6)	2.2
Non-land-based attributes								
Non-farm activities, ZMW	397.0 (825.4)	4.3	374.7 (869.1)	2.8	349.7 (711.6)	5.9	374.2 (806.9)	3.9
Total household income	9253.4 (6579.7)	100	13,528.7 (13,841.2)	100	5913.8 (3653.8)	100	9697.7 (9770.2)	100

B. Distribution of household income across distance categories

Household sources of income	Distance categories					
	Close-distance (n = 314)		Medium-distance (n = 612)		Remote-distance (n = 197)	
	Mean (SD)	Share of the sample (%)	Mean (SD)	Share of the sample (%)	Mean (SD)	Share of the sample (%)
Land-based attributes						
Forest products (unprocessed), ZMW	2746.3 (2657.9)	27.0	2500.3 (2653.8)	26.9	2851.7 (2769.5)	27.9
Charcoal production, ZMW	2809.7 (7642.1)	27.6	1881.6 (5783.9)	20.3	2354.1 (7602.3)	23.1
Crop production, ZMW	3102.5 (4059.6)	30.5	3469.1 (4134.7)	37.3	3579.5 (3828.6)	35.1
Livestock production, ZMW	814.2 (1636.1)	8.0	841.9 (1546.3)	9.1	841.8 (1460.3)	8.2
Capture fish, ZMW	35.9 (110.7)	0.4	37.5 (117.3)	0.4	38.0 (109.9)	0.4
Off-farm activities, ZMW	210.3 (436.0)	2.1	191.4 (369.7)	2.1	275.9 (549.5)	2.7
Non-land-based attributes						
Non-farm activities, ZMW	454.1 (899.2)	4.5	366.5 (805.1)	3.9	270.6 (628.1)	2.7
Total household income, ZMW	10,173.0 (10,609.8)	100	9288.4 (9112.2)	100	10,211.6 (10,329.3)	100

[a] Incomes are continuous and calculated as net incomes in Zambian Kwacha (ZMW) (i.e., revenue minus the cost of production). At the time of data collection, 1USD = 10.13 ZMW (Bank of Zambia, 2018).
[b] Standard deviation (SD) in parentheses.

contributed approximately 85% of total household income, while the remaining 15% of total household income was accounted for by capture fish, off-farm and non-farm income (Table 2A).

4.3. *Crop productivity in distance categories and across study provinces*

Table 3 shows subsistence (cereals) and commercial (vegetable and legumes) crop productivity in distance categories and across the study provinces. In the North-Western and the Copperbelt Province, we observe high crop productivity (subsistence and commercial) at medium and remote-distance categories compared to the Eastern Province. In comparison, we observe high crop productivity at close-distance categories in the Eastern Province (Table 3 A, B and C). However, the productivity of cereals and legumes in the Copperbelt Province was generally low compared to the productivity in the North-Western and Eastern Provinces, except for vegetable productivity.

In absolute terms, legumes production had the largest absolute contribution, mostly ranging from 3634.6 to 4959.7 ZMW/ha/year (ZMW ha^{-1} yr^{-1}) compared to vegetable and cereals production in distance categories and across all the study provinces (Table 3 A, B and C). Overall, there are no substantial differences in different crops' contribution across distance categories for the entire study, but the proportion of different crops within the provinces is evident (Table 3 A, B and C).

4.4. *Deforestation rates across distance categories in the study area*

We estimated deforestation rates across three distance categories in the North-Western Province (early transition), the Copperbelt Province (mid-transition), and Eastern Province (late-transition) for six years between 2013 and 2018. Generally, the rates of deforestation in the close-distance, medium and remote-distance categories varied across all the provinces (Table 4). The North-Western Province and Copperbelt Province, in particular, had decreasing rates of deforestation across distance categories but maintained relatively higher rates of deforestation compared to the Eastern Province. On the other hand, the Eastern Province had increasing deforestation rates across distance categories (Table 4).

In addition, the Copperbelt Province had the highest average annual rate of deforestation of approximately −1.15% compared to −0.48% in the North-Western and − 0.29% in the Eastern Province (Table 4). Simultaneously, the Copperbelt and the North-Western Provinces have the highest proportion of forest cover, estimated at 67.6% and 85.6%, respectively, compared with the Eastern Province (Table 4). These rates

Table 3

A. Cereals productivity in distance categories and across study provinces.

Distance category	Provinces						Whole sample (n = 1123)	
	North-Western (n = 374)		Copperbelt (n = 394)		Eastern (n = 355)			
	Mean (SD)	Share of the Sample (%)	Mean (SD)	Share of the Sample (%)	Mean (SD)	Share of the Sample (%)	Mean (SD)	Share of the Sample (%)
Close	2052.0 (2146.1)	32.2	971.2 (1144.3)	34.9	1505.7 (2181.5)	39.3	1468.6 (1879.3)	34.3
Medium	2113.8 (2231.2)	33.1	944.1 (1339.4)	34.0	1293.7 (1473.4)	33.8	1466.2 (1803.1)	34.3
Remote	2215.9 (2147.5)	34.7	865.5 (864.0)	31.1	1030.5 (1160.6)	26.9	1345.1 (1579.9)	31.4

B. Vegetable productivity in distance categories and across study provinces

Distance category	Provinces						Whole sample (n = 1123)	
	North-Western (374)		Copperbelt (n = 394)		Eastern (n = 355)			
	Mean (SD)	Share of the Sample (%)	Mean (SD)	Share of the Sample (%)	Mean (SD)	Share of the Sample (%)	Mean (SD)	Share of the Sample (%)
Close	1185.8 (1490.1)	24.8	1723.5 (3487.3)	33.7	725.6 (2524.0)	61.2	1266.2 (2731.6)	33.3
Medium	1945.2 (3044.5)	40.7	1790.0 (3682.0)	35.0	187.1 (814.7)	15.8	1298.7 (2883.0)	34.2
Remote	1650.5 (1776.2)	34.5	1603.5 (3765.0)	31.3	271.9 (1230.9)	23.0	1233.3 (2703.0)	32.5

C. Legumes productivity in distance categories and across study provinces

Distance category	Provinces							
	North-Western (n = 374)		Copperbelt (n = 394)		Eastern (n = 355)		Whole sample (n = 1123)	
	Mean (SD)	Share of the Sample (%)	Mean (SD)	Share of the Sample (%)	Mean (SD)	Share of the Sample (%)	Mean (SD)	Share of the Sample (%)
Close	3634.6 (4825.5)	28.1	973.8 (2193.9)	29.9	2180.4 (2312.0)	39.1	2167.0 (3468.2)	30.3
Medium	4319.6 (4981.4)	33.4	947.4 (2482.2)	29.0	1924.9 (2467.3)	34.5	2442.3 (3813.3)	34.2
Remote	4959.7 (5520.6)	38.4	1340.7 (2744.6)	41.1	1469.7 (1583.1)	26.4	2535.4 (4007.2)	35.5

Crop productivity is net crop income per hectare per year (ZMW ha^{-1} yr^{-1}).

Table 4

Extent of forest cover and average annual rates of deforestation in distance categories across study provinces during 2013–2018.

Distance categories	North-Western Province (Early transition)			Copperbelt Province (Mid transition)			Eastern Province (Late transition)		
	Area (km^2)	FC[a] (%)	Deforestation[b] (%)	Area (km^2)	FC[a] (%)	Deforestation[b] (%)	Area (km^2)	FC[a] (%)	Deforestation[b] (%)
Close-distance	296.66	82.17	−0.68	548.31	68.63	−1.28	89.67	14.93	−0.21
Medium-distance	494.27	87.88	−0.38	604.00	72.98	−1.04	237.62	21.59	−0.28
Remote-distance	952.39	86.68	−0.39	518.81	61.24	−1.13	427.80	22.04	−0.37
Average	581.10	85.58	−0.48	557.04	67.62	−1.15	251.70	19.52	−0.29

[a] FC (Forest Cover) is calculated as the share of area with tree cover above 30% for the year 2000.

[b] Deforestation is the average annual rates of deforestation for the 2013–2018 period, considering the net loss of areas with tree cover above 30% (Hansen et al., 2013).

indicate that regions with the largest proportion of forest cover continue to experience higher deforestation rates in our study areas. Accordingly, only areas close to settlements with high forest cover are prone to high deforestation compared to remote areas, but this trend is reversed in the low forest region.

4.5. Effects of household-level attributes on deforestation in the study provinces

Table 5 shows the generalised ordered logistic regression estimates for North-Western Province, Copperbelt and the Eastern Province (regional models), while Table A1 shows estimates for the whole sample. The whole sample model shows the average causative effects of household-level attributes on deforestation for all three regions, while regional models show region-specific outcomes. The whole sample and regional models showed differing impacts of household-level attributes on deforestation patterns. In this study, we focus on identifying regional causes of deforestation. As such, the results described here are mainly for the regional model (Table 5a, b, and c).

The socio-demographic attributes that were significantly associated with deforestation patterns are household size, ethnicity, educational level of household head, and duration of residence in the village (Table 5 a, b, and c). However, these variables were not always significant in all regions, and their effect varies across regions. In the North-Western Province, we found that large household size increased the likelihood of medium deforestation and high deforestation by 0.55 and 3.1 percentage points, respectively, holding all other factors constant (Table 5a). However, we note that belonging to the largest ethnic group

Table 5
Generalised ordered logit model results of household-level attributes on deforestation patterns in the study provinces (part 1).

a. North-Western Province

Variables	Marginal effects		
	Deforestation levels		
	Low	Medium	High
Socio-demographic attributes			
Age of household head, years	0.0000827 (0.0171)	−0.0000127 (0.00262)	−0.00007 (0.0145)
Male-headed household, 1 = Yes; 0 = No	0.0183 (0.0411)	−0.00269 (0.00584)	−0.0156 (0.0353)
Head of household attained above primary education, 1 = Yes; 0 = No	−0.0194 (0.0373)	0.00278 (0.00506)	0.0166 (0.0323)
Household size, Number of members	−0.0361** (0.016)	0.00553* (0.00305)	0.0306** (0.0134)
Duration of residence in the village, years	0.0262 (0.0215)	−0.00401 (0.00358)	−0.0222 (0.0181)
Household head belongs to the largest group, Lunda = 1; Others =0	0.0929** (0.0381)	−0.0142* (0.00824)	−0.0787** (0.0309)
Land-based attributes			
Total size of patches land owned, ha	0.0418* (0.0228)	−0.0064 (0.00413)	−0.0354* (0.0192)
Livestock, tropical livestock unit (TLU)	0.0463* (0.0273)	−0.0071 (0.00463)	−0.0392* (0.0232)
Forest products (unprocessed), ZMW	0.0365* (0.0218)	−0.00559 (0.00371)	−0.0309* (0.0185)
Charcoal production, ZMW	0.0489 (0.0688)	−0.00749 (0.011)	−0.0414 (0.0581)
Capture fish, ZMW	0.0420*** (0.0114)	−0.00644*** (0.00245)	−0.0356*** (0.0098)
Off-farm income, ZMW	0.00848 (0.0143)	−0.0013 (0.00223)	−0.00718 (0.0121)
Cereals crop production, ZMW/ha/yr[a]	0.0284** (0.0137)	−0.0194*** (0.00538)	−0.00903 (0.012)
Vegetable production, ZMW/ha/yr	0.00199 (0.0199)	0.00381 (0.01)	−0.0058 (0.0198)
Legumes production, ZMW/ha/yr	0.0203 (0.0134)	−0.00923* (0.0049)	−0.0111 (0.0112)
Non-land-based attributes			
Non-farm income, ZMW	0.0452*** (0.016)	−0.00692** (0.00299)	−0.0382*** (0.0138)
Location attributes			
Household had access to permanent road, 1 = Yes; 0 = No	−0.102** (0.0471)	0.0212* (0.0124)	0.0811** (0.0356)
Household's distance to main road, walking time (minutes)	0.0913*** (0.012)	−0.0140*** (0.00458)	−0.0773*** (0.01)
Household's distance to the centre of the village, walking time (minutes)	−0.0349 (0.0294)	0.00535 (0.00487)	0.0296 (0.0247)
Landscape has forest reserve, 1 = Yes; 0 = No	0.487*** (0.0435)	0.0364 (0.0258)	−0.523*** (0.047)
Land-use patch in medium-distance (close is base outcome)	0.134*** (0.0404)	−0.0252 (0.0183)	−0.109*** (0.0299)
Land-use patch in remote-distance (close is base outcome)	−0.198*** (0.0393)	−0.0754*** (0.0279)	0.273*** (0.0497)
Log-likelihood	−257.05		
Pseudo R^2	0.37		
N	374		

b. Copperbelt Province

Variables	Marginal effects		
	Deforestation levels		
	Low	Medium	High
Socio-demographic attributes			
Age of household head, years	−0.0335 (0.0227)	0.00737 (0.00535)	0.0261 (0.0177)
Male-headed household, 1 = Yes; 0 = No	−0.0702 (0.0662)	0.0193 (0.0219)	0.051 (0.0447)
Head of household attained above primary education, 1 = Yes; 0 = No	−0.0872* (0.0449)	0.0145** (0.00713)	0.0727* (0.04)
Household size, Number of members	0.0424** (0.0205)	−0.00933* (0.00502)	−0.0330** (0.0161)
Duration of residence in the village, years	0.0544** (0.0239)	−0.0120** (0.00594)	−0.0424** (0.0189)
Household head belongs to the largest group, Lamba = 1; Others =0	−0.0457 (0.0417)	0.0101 (0.00954)	0.0356 (0.0326)
Land-based attributes			
Total size of patches of land owned, ha	−0.00649 (0.0148)	0.00143 (0.00328)	0.00506 (0.0115)
Livestock, tropical livestock unit (TLU)	−0.0324* (0.018)	0.00714* (0.00434)	0.0253* (0.0141)
Forest products (unprocessed), ZMW	−0.107*** (0.0216)	0.0236*** (0.0081)	0.0836*** (0.0163)
Charcoal production, ZMW	−0.0122 (0.0152)	0.00268 (0.00338)	0.00949 (0.0119)
Capture fish, ZMW	0.0576* (0.0307)	−0.0127* (0.00715)	−0.0449* (0.0243)
Off-farm income, ZMW	−0.00662 (0.0278)	0.00146 (0.00616)	0.00516 (0.0217)
Cereals crop production, ZMW/ha/yr	−0.0759** (0.0349)	0.00358 (0.0109)	0.0723** (0.0283)
Vegetable production, ZMW/ha/yr	0.00673 (0.0187)	−0.0093 (0.0066)	0.00258 (0.0139)
Legumes production, ZMW/ha/yr	0.0471 (0.0354)	−0.0117 (0.0122)	−0.0354 (0.0264)
Non-land-based attributes			
Non-farm income, ZMW	0.0382* (0.0201)	−0.00841* (0.00478)	−0.0297* (0.0158)
Location attributes			
Household had access to permanent road, 1 = Yes; 0 = No	0.0731 (0.0511)	−0.0177 (0.0139)	−0.0554 (0.0378)
Household's distance to main road, walking time (minutes)	0.048 (0.0415)	−0.0106 (0.00958)	−0.0374 (0.0324)
Household's distance to the centre of the village, walking time (minutes)	0.0392* (0.0225)	−0.00864 (0.00527)	−0.0306* (0.0177)
Landscape has forest reserve, 1 = Yes; 0 = No	0.0296 (0.0495)	−0.00648 (0.0107)	−0.0231 (0.0389)
Land-use patch in medium-distance (close is base outcome)	0.224*** (0.0431)	−0.0283 (0.0182)	−0.196*** (0.0368)
Land-use patch in remote-distance (close is base outcome)	0.054 (0.051)	0.0123 (0.0155)	−0.0663 (0.0513)
Log-likelihood	−364.48		
Pseudo R2	0.15		
N	394		

c. Eastern Province

(continued on next page)

Table 5 (*continued*)

c. Eastern Province

Variables	Marginal effects		
	Deforestation levels		
	Low	Medium	High
Variables	Marginal effects		
	Deforestation levels		
	Low	Medium	High
Socio-demographic attributes			
Age of household head, years	−0.00663 (0.0187)	0.00128 (0.00358)	0.00536 (0.0151)
Male-headed household, 1 = Yes; 0 = No	0.0244 (0.0392)	−0.00467 (0.00742)	−0.0198 (0.0318)
Head of household attained above primary education, 1 = Yes; 0 = No	0.0406 (0.0439)	−0.00831 (0.00948)	−0.0323 (0.0346)
Household size, Number of members	−0.00514 (0.0177)	0.000988 (0.00342)	0.00415 (0.0143)
Duration of residence in the village, years	−0.0427** (0.0175)	0.00822** (0.00391)	0.0345** (0.0139)
Household head belongs to the largest group, Nsenga = 1; Others =0	−0.034 (0.0967)	0.00654 (0.0186)	0.0274 (0.0781)
Land-based attributes			
Total size of patches of land owned, ha	−0.0593 (0.061)	0.0114 (0.0117)	0.0479 (0.0495)
Livestock, tropical livestock unit (TLU)	0.0322* (0.0195)	−0.0062 (0.00383)	−0.026 (0.0159)
Forest products (unprocessed), ZMW	−0.00696 (0.0302)	0.00134 (0.00588)	0.00562 (0.0243)
Charcoal production, ZMW	−0.138 (0.116)	0.0266 (0.0218)	0.112 (0.0948)
Capture fish, ZMW	−0.0153 (0.036)	0.00294 (0.00691)	0.0123 (0.0291)
Off-farm income, ZMW	−0.00288 (0.0158)	0.000555 (0.00306)	0.00233 (0.0128)
Cereals crop production, ZMW/ha/yr	−0.0438** (0.0187)	0.00152 (0.00535)	0.0423*** (0.016)
Vegetable production, ZMW/ha/yr	−0.0571 (0.0396)	0.0207*** (0.00798)	0.0364 (0.0367)
Legumes production, ZMW/ha/yr	0.0117 (0.0313)	−0.0106 (0.0107)	−0.00104 (0.0244)
Non-land-based attributes			
Non-farm income, ZMW	0.0156 (0.0207)	−0.003 (0.004)	−0.0126 (0.0167)
Location attributes			
Household had access to permanent road, 1 = Yes; 0 = No	−0.0932*** (0.0327)	0.0175** (0.00681)	0.0757*** (0.0266)
Household's distance to main road, walking time (minutes)	0.0761 (0.0915)	−0.0146 (0.0172)	−0.0614 (0.0746)
Household's distance to the centre of the village, walking time (minutes)	0.0741*** (0.0206)	−0.0142*** (0.00511)	−0.0598*** (0.0163)
Landscape has forest reserve, 1 = Yes; 0 = No	0.553*** (0.0378)	−0.0980*** (0.0336)	−0.455*** (0.0351)
Land-use patch in medium-distance (close is base outcome)	−0.301*** (0.047)	0.0721** (0.0299)	0.229*** (0.0265)
Land-use patch in remote-distance (close is base outcome)	−0.355*** (0.0569)	0.0672** (0.03)	0.288*** (0.0435)
Log-likelihood	−242.68		
Pseudo R2	0.37		
N	355		

*** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$. Standard errors in parentheses.
dy/dx for factor levels is the discrete change from the base level.
Outliers and multilinearity checks were conducted before performing econometric estimations.
[a]Crop income effects on deforestation are further analysed across distances categories in each study province (Table 6).

in the North-Western Province was associated with less likelihood of medium deforestation and high deforestation. The percentage points are 1.4 and 7.9, respectively, holding all other factors constant (Table 5a).

In the Copperbelt Province, household heads that attained above primary education are associated with the likelihood of increased medium deforestation and high deforestation (Table 5b). The percentage points are 1.5 and 7.3, respectively, holding all other factors constant (Table 5b). Additionally, we found that large household size and residence duration in the village are associated with a reduced likelihood of medium deforestation and high deforestation (Table 5b).

While in the Eastern Province, the household's duration of residence in the village was associated with an increased likelihood of medium deforestation and high deforestation. The percentage points are 1.2 and 4.2, respectively, holding all other factors constant (Table 5c).

Our findings demonstrate that households' socio-demographic characteristics are important factors for explaining variations in deforestation patterns within provinces in the Miombo areas of Zambia. However, we cannot find consistent regional patterns attributed to the biophysical background (i.e., North-Western and Copperbelt vs Eastern Province) nor along potential forest transition phases (i.e., North-Western vs Copperbelt and Eastern Province).

Regarding land and non-land-based attributes, we found that in the North-Western Province, the impact of land and non-land-based variables was mainly negative in relation to medium deforestation and high deforestation (Table 5a). Specifically, we note with surprise that large patches of land owned, livestock units and increased income from unprocessed forest products (mainly fuelwood) was significant and associated with reduced medium deforestation and high deforestation. An increase in cereals crop productivity (subsistence crop production) reduced the likelihood of medium deforestation by 1.9 percentage points, holding all other factors constant. An increase in legumes crop productivity (commercial crop production) reduced the likelihood of medium deforestation by 0.9 percentage points, holding all other factors constant (Table 5a). For the non-land-based attributes, we note that increases in non-farm incomes significantly reduced the likelihood of medium deforestation by 0.69 percentage points and the likelihood of high deforestation by 3.8 percentage points, holding all other factors constant (Table 5a).

On the contrary and with regard to the Copperbelt Province, the land-based attributes that were significant, but in different directions are livestock units owned, income from unprocessed forest products, capture fish, and cereals crop production (Table 5b). Notably, we found that livestock units owned increased the likelihood of medium deforestation (0.71 percentage points) and the likelihood of high deforestation by 2.5 percentage points, holding all other factors constant. In addition, increased incomes from forest products (unprocessed products) in the Copperbelt Province increased the likelihood of medium deforestation by 2.4 percentage points and increased the likelihood of high deforestation by 8.4 percentage points, holding all other factors constant (Table 5b).

However, we note that while charcoal production is positively associated with medium deforestation and high deforestation in the

Copperbelt Province, it was not statistically significant (Table 5b), despite contributing the largest proportion of the household total income (Table 2A). However, a correlation between charcoal income and deforestation patterns in the Copperbelt Province is 0.15 (i.e., Pearson's $r = 0.15$), and significant, which indicates that charcoal production is positively related to patterns of deforestation in the Copperbelt Province. This finding means that charcoal production can increase the likelihood of medium deforestation and high deforestation (see Table A1), but the effects at regional levels are more apparent when other household characteristics are not considered (i.e., when other households attributes are controlled).

Furthermore, we found that cereals crop productivity (subsistence crop production) increased the likelihood of high deforestation in the Copperbelt Province. The percentage points are 7.2, holding all other factors constant (Table 5b). While an increase in income from capture fish was associated (significant at 0.1 alpha) with a reduced likelihood of medium deforestation and high deforestation.

With regard to non-land-based attributes, we note that the increase in income from non-farm activities in the Copperbelt Province was associated with a lower probability of medium deforestation and high deforestation. The percentage points are 0.84 and 2.9, respectively, holding all other factors constant (Table 5b).

In the Eastern Province, most production types are positively related to medium and high deforestation patterns (though not all of them are significant) except for livestock units and non-farm income. In particular, cereals crop productivity (subsistence crop) and vegetable productivity (commercial crop) was significant and increased the likelihood of high deforestation and medium deforestation. The percentage points are 4.2 and 2.1, respectively, holding all other factors constant (Table 5c).

Together, these findings demonstrate that livelihood variables have major effects on deforestation patterns, although their influence is regionally distinct. However, the impact of non-farm incomes and legumes production on medium deforestation and high deforestation patterns was consistently negative across all regions but not always significant.

With regard to the location attributes, we note that the location variables in the North-Western Province were mainly significant, except for the distance to the centre of the village (Table 5a). Specifically, we found that access to permanent roads was significant and increased the likelihood of medium deforestation and the likelihood of high deforestation by 2.1 and 8.1 percentage points, respectively, holding all other factors constant (Table 5a). At the same time, we found that increased walking distance from the household to the main road reduced the likelihood of medium deforestation by 1.4 percentage points and the likelihood of high deforestation by 7.7 percentage points, holding all other factors constant (Table 5a). Besides, restrictions on access to and use of forest resources were significantly associated with a reduced likelihood of high deforestation. The percentage points are by 52.3, while all other factors remain constant (Table 5a). The patches of land-use (distance categories) were significant and in different directions, which indicates that the distances of land-use patches from households' homesteads affect variation in deforestation patterns in the North-Western Province (Table 5a).

In the Copperbelt Province, we found that increased walking distance to the village centre significantly reduced the likelihood of high deforestation by 3.1 percentage points, holding all other factors constant. Simultaneously, the location of patches of land-use in the medium-distance category was associated (significant at 0.01 alpha) with a reduced likelihood of high deforestation (Table 5b).

In the Eastern Province, we found that access to permanent roads increased the likelihood of medium deforestation by 1.8 percentage points and the likelihood of high deforestation by 7.6 percentage points, holding all other factors constant (Table 5c). At the same time, increased walking distance to the centre of the village reduced the likelihood of medium deforestation and the likelihood of high deforestation. The percentage points are 1.4 and 5.9, respectively, holding all other factors constant (Table 5c). Furthermore, we found that restrictions on access to and using forest resources in the Eastern province were significantly associated with a reduced likelihood of medium deforestation and high deforestation. The percentage points are 9.8 and 45.5, respectively, holding all other factors constant. Lastly, the location of patches of land use in the medium-distance and remote-distance category were associated with increased medium deforestation and high deforestation (Table 5c).

Our findings with regard to the location attributes show that the effects of location attributes on deforestation patterns are distinct across regions. This finding demonstrates that variations in distances determine agricultural land-use and deforestation patterns in our study area. This result is further investigated in section 4.6.

4.6. *Effects of the spatial distribution of agricultural land-use on regional deforestation patterns*

Table 6 shows the implications of the spatial distribution of agricultural land-use on regional deforestation patterns. While we noted that deforestation is strongly linked to agricultural land-use and patch location (Table 5), the effects of crop productivity on deforestation patterns are more evident across distance categories, which vary along the transition (Table 6 a, b and c).

In the North-Western Province, we found that increased cereals crop productivity (subsistence crop production) increased the likelihood of medium deforestation and high deforestation at close-distance and remote-distance category (Table 6a). Additionally, we note that the effects of commercial crops production (i.e., vegetable and legumes productivity) on the likelihood of high deforestation were consistently negative at close-distance and medium-distance category. However, these commercial crops' effects were not statistically significant across distance categories in the North-Western Province (Table 6a).

In the Copperbelt Province, an increase in cereals crop productivity was positively associated with the likelihood of high deforestation at a close-distance category. In comparison, an increase in vegetable (commercial crop) productivity reduced the likelihood of high deforestation in the medium-distance category (Table 6b). Together, these results support the earlier findings in Table 4, where we observed high deforestation rates at closer distances and lower deforestation rates further away from the households. These findings demonstrate that subsistence crop production, rather than commercial crop production, is associated with high deforestation at closer distances from the households in the Copperbelt Province.

Regarding the Eastern Province, we found an increase in cereals crop productivity increased the likelihood of higher deforestation (i.e., medium deforestation and high deforestation) at the medium-distance category (Table 6c). At the same time, we find that increased productivity of vegetables is associated with higher deforestation in the close-distance category.

Overall, our findings demonstrate that agricultural land-use and patch locations are important aspects associated with deforestation patterns in the North-Western, Copperbelt and the Eastern Province of Zambia.

c. Eastern Province

Variables	Marginal effects		
	Deforestation levels		
	Low	Medium	High
Crops productivity at varying distance categories			
Cereals crop productivity, ZMW/ha/yr			
Close-distance	0.00328 (0.0300)	−0.00181 (0.0165)	−0.00148 (0.0135)

(continued on next page)

Table 6
Generalised ordered logit model results of the spatial distribution of agricultural land-use on deforestation patterns in the study provinces (part 2)[a].

a. North-Western Province

Variables	Marginal effects		
	Deforestation levels		
	Low	Medium	High
Crop productivity at varying distance categories			
Cereals crop productivity, ZMW/ha/yr			
Close-distance	−0.0272 (0.0244)	0.0691*** (0.0199)	−0.0290 (0.0193)
Medium-distance	0.00419 (0.00411)	−0.0233*** (0.00695)	−0.0312* (0.0182)
Remote-distance	0.0230 (0.0210)	−0.0458*** (0.0137)	0.0602* (0.0352)
Vegetable productivity, ZMW/ha/yr			
Close-distance	0.0800 (0.0583)	−0.0332 (0.0206)	−0.000103 (0.0371)
Medium-distance	−0.0124 (0.0119)	0.0112 (0.00706)	−0.000111 (0.0399)
Remote-distance	−0.0677 (0.0484)	0.0220 (0.0137)	0.000214 (0.0770)
Legumes crop productivity, ZMW/ha/yr			
Close-distance	0.0229 (0.0241)	0.0282 (0.0193)	−0.0125 (0.0156)
Medium distance	−0.00353 (0.00397)	−0.00950 (0.00645)	−0.0135 (0.0148)
Remote-distance	−0.0193 (0.0207)	−0.0187 (0.0130)	0.0260 (0.0298)
Observations	374	374	374

b. Copperbelt Province

Variables	Marginal effects		
	Deforestation levels		
	Low	Medium	High
Crops productivity at varying distance categories			
Cereals crop productivity, ZMW/ha/yr			
Close-distance	−0.157*** (0.0592)	−0.0178 (0.0180)	0.175*** (0.0615)
Medium-distance	−0.0430 (0.0443)	0.0186 (0.0193)	0.0244 (0.0253)
Remote-distance	−0.0310 (0.0908)	0.00261 (0.00853)	0.0284 (0.0833)
Vegetable productivity, ZMW/ha/yr			
Close-distance	−0.0234 (0.0237)	−0.00266 (0.00365)	0.0261 (0.0261)
Medium-distance	0.0517* (0.0305)	−0.0224* (0.0135)	−0.0293* (0.0176)
Remote-distance	−0.0537 (0.0351)	0.00452 (0.00792)	0.0491 (0.0318)
Legumes crop productivity, ZMW/ha/yr			
Close-distance	0.0447 (0.0460)	0.00508 (0.00754)	−0.0497 (0.0514)
Medium-distance	0.0667 (0.0596)	−0.0289 (0.0260)	−0.0378 (0.0341)
Remote-distance	0.00479 (0.0551)	−0.000404 (0.00463)	−0.00439 (0.0505)
Observations	394	394	394

(*continued*)

c. Eastern Province

Variables	Marginal effects		
	Deforestation levels		
	Low	Medium	High
Medium-distance	−0.0679*** (0.0231)	0.00443** (0.00210)	0.0635*** (0.0222)
Remote-distance	−0.0312 (0.0575)	0.00164 (0.00284)	0.0296 (0.0551)
Vegetable productivity, ZMW/ha/yr			
Close-distance	−0.112** (0.0467)	0.0614** (0.0294)	0.0502** (0.0229)
Medium-distance	−0.0215 (0.0596)	0.00140 (0.00359)	0.0201 (0.0560)
Remote-distance	−0.0915 (0.0777)	0.00480 (0.00599)	0.0867 (0.0743)
Legumes crop productivity, ZMW/ha/yr			
Close-distance	0.0960 (0.0635)	−0.0528 (0.0347)	−0.0432 (0.0319)
Medium-distance	−0.00223 (0.0322)	0.000146 (0.00211)	0.00209 (0.0301)
Remote-distance	−0.0668 (0.105)	0.00350 (0.00713)	0.0633 (0.0985)
Observations	355	355	355

(*continued on next column*)

*** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$. Standard errors in parentheses. Table 6a, b, and c are continuations of the generalised ordered logistic regression model; here, we estimate interactions between crop income (crop productivity) and distance categories (i.e., how crop incomes vary across distance categories)".

5. Discussion

5.1. Deforestation across distance categories and forest transition context

An analytical framework that incorporates agricultural land-use and forest cover suggests that deforestation varies spatially along the forest transition (Fig. 1). This highlights the importance of using distances to land-use patches and forest cover data to understand deforestation better and develop case-sensitive measures for addressing deforestation and sustainable development. Based on this framework (Fig. 1), we observed a decreasing pattern of deforestation rates across distance categories in the early- and mid-transition compared to the late-transition. Statistical analysis confirms these observations.

We found that deforestation varies across landscapes and regions; the mid-transition (Copperbelt Province) had the highest, −1.15% average annual rate of deforestation compared to the early-transition (North-Western Province), −0.48% and the late-transition (Eastern Province), −0.29%. Although these rates vary and appear to be lower compared to the rates reported across the region (e.g., Mozambique, −2.8 ± 1.9% per year (Ryan et al., 2014) and Malawi, −4.7% per year (McNicol et al., 2018)), they are comparable to the rates reported in Zambia (e.g., − 0.5 to − 0.6% per year, FAO, 2015; and − 0.54 to −3.05% per year, Phiri et al., 2019a). These contrasting rates between our findings and the previous studies are partly due to different definitions of deforestation; we used the concept of Hansen et al. (2013), which maps areas of complete tree cover loss, while data provided in FAO (2015) are based on extrapolated rates. While other studies used aggregated large-scale data at the national level with a longer period, we estimated deforestation covering a short period (6 years) in areas of households influences across landscapes and regions. Thus, our findings recognise landscapes and regional differences in deforestation. Our results mean that in the agrarian economies (Angelsen et al., 2014; Davis et al., 2017; Gibbs et al., 2010), estimating household areas of influence (spatial units, Fig. 2) is important in understanding the scale and patterns of deforestation along the forest transition.

Overall, our results support the forest transition concept explaining variations in deforestation along a forest transition gradient (Rudel et al., 2005). As confirmed by our findings, the changes in deforestation patterns across distance categories suggest that the von Thünen framework (distances) could be appropriate for testing whether economic reasons are driving deforestation trends (Angelsen, 2007). In the subsections that follow, these observations are highlighted and discussed in greater detail.

Our results provide empirical evidence following Angelsen (2007), who suggested a theoretical relationship between agricultural land-use and the forest transition. While we found systematic patterns of decreasing deforestation across distance categories further from households in the early-and mid-forest transition regions, we observed increasing deforestation patterns across distance categories further from households in the late transition. Additionally, low average annual deforestation rates were revealed in the late transition compared to early and mid-transition regions. These findings are consistent with previous studies that explain higher deforestation in areas closer to settlements (Call et al., 2017; McNicol et al., 2018; Sandker et al., 2017). The spatial patterns suggest deforestation might be linked to the subsistence needs of rural households. Our findings also indicate that annual deforestation does not often amount to cumulative rates over time but can be cyclical over time (Wolfersberger et al., 2015). This outcome challenges the view that explains high deforestation in the late transition region due to cumulative deforestation occurring over time (Sandker et al., 2017; Schielein and Börner, 2018).

5.2. *Household-level attributes and deforestation along a forest transition gradient*

Past deforestation studies reveal that causes of deforestation are multiple but vary across landscapes and regions (Call et al., 2017; Etter et al., 2006; Geist and Lambin, 2002). These factors can include households' socio-demographic attributes, land and non-land-based attributes, and location characteristics (Babigumira et al., 2014; Mena et al., 2006; Twongyirwe et al., 2018). Our results are in agreement with most of these studies but challenge those using aggregated, large-scale (Rudel, 2013) or country-level data (Babigumira et al., 2014; Hosonuma et al., 2012; Phiri et al., 2019b) to estimate the effects of household-level attributes on deforestation.

Following previous studies explaining the role of socio-demographic attributes (Babigumira et al., 2014; Mena et al., 2006), we found that households' socio-demographic characteristics distinctly affect deforestation patterns across our study provinces (i.e., the North-Western Province, Copperbelt, and the Eastern Province). This result means that causes of deforestation are regional and that socio-demographic attributes differently influence variation in deforestation patterns in the Miombo landscapes of Zambia. In particular, we note that large household size in the North-Western Province is significant and positively associated with increased high deforestation. While in the Copperbelt Province, large household size is negatively associated with high deforestation. Partly, this result means that rural population pressure in the form of household-labour subdivision can strongly drive deforestation (Ferrer Velasco et al., 2020; Mena et al., 2006). While on the other hand, this finding indicates that rural households-labour subdivision broadens households labour opportunities, which can reduce pressures on forests (DeFries et al., 2010). Together, these findings mean that policies aimed at reducing deforestation among the rural population can only be effective if regional dynamics are considered in policy design.

Additionally, we note that households whose heads attained above primary education were positively associated with high deforestation in the Copperbelt Province. This finding corresponds to our observations in the Copperbelt and elsewhere where the local elites who often constitute the majority of the traditional governance structures take advantage of the patronage that exists within the traditional system to engage in exploitative land and forest resources use (Chitonge et al., 2017; Payne and Durand-Lasserve, 2012). The educated rural elites are often connected within the village and with intermediary actors (usually based in urban areas) (Sitko and Jayne, 2014). As such, these rural elites often take advantage of market opportunities linked to land transactions and the use of forest products, which may increase the pressure on the remaining forests (DeFries et al., 2010). However, this finding challenges the view that better education can increase the level of civic competence of rural households to engage in sustainable forest-based practices that are considered non-exploitative (Kamanga et al., 2009; Miyamoto, 2020).

Our analysis also suggests that the effects of residence duration on deforestation are only apparent when households have lived in the areas for more than fifteen (15) years (Tables 1 and 5). In rural Zambia, admission to the village is subject to acceptance by the traditional authority, whose rules vary across provinces (Chanock, 1985; Kalinda et al., 2008). Accordingly, households that stay longer in the village tend to understand the local processes over time and, therefore, are likely to engage in activities that can affect deforestation (Dolisca et al., 2007; Giliba et al., 2011).

In agreement with the previous studies and without exception, we found that the size of land-use patches owned, livestock units, forest income, fish capture, and crop productivity showed significant effects (though not in all provinces) on deforestation patterns within the provinces (Call et al., 2017; Kissinger et al., 2012; Ojeda Luna et al., 2020; Rudel, 2013). Additionally, while it is noteworthy that households with large land-use patches are associated with a decline in high deforestation, especially in the North-Western Province, the land-use patch's impact is significantly weak ($p < 0.1$). In Zambia and especially in the rural areas, the land is often customarily owned, and the chiefs regulate the acquisition and land use (Payne and Durand-Lasserve, 2012). Such regulated acquisition and land-use practices appear to explain reduced deforestation in the North-Western Province. However, as noted elsewhere in Zambia, assured ownership of the traditional land does not solve the challenges of sustainable forest management (Kazungu et al., 2020).

Contrary to studies explaining deforestation as mainly linked to commercial crop production in the tropical and subtropical areas (DeFries et al., 2010; Leblois et al., 2017; Miyamoto, 2020; Ryan et al., 2017), we found that legumes productivity (commercial crop) was negative across all the provinces but significant ($p < 0.1$) only in the North-Western Province. On the other hand, we found a strong ($p < 0.01$) positive association between commercial crop production (vegetable production) and medium deforestation in the Eastern Province (late forest transition). In part, this finding means that agricultural intensification (von Thünen, 1826) can effectively reduce the likelihood of high deforestation in agrarian economies. However, our results suggest that crop intensification alone cannot strongly be associated with deforestation patterns in the smallholder dominated Miombo forest landscapes of Zambia (Phiri et al., 2019b; Vinya et al., 2011).

Furthermore, we note that subsistence crop production was strongly ($p < 0.05$) linked to higher deforestation, but the effects were in different directions across provinces. Although this study's focus was on smallholder production, our finding indicates that the need to sustain livelihoods could mainly explain the observed trends in deforestation. However, the productivity of land-use patches, demographic trends and competition from other land uses such as extraction of forest products also play a significant role in these processes, as shown in Tables 2 and 5 (see also Handavu et al., 2019).

For non-land-based attributes, we found that increases in non-farm income (i.e., wages, self-employment and remittances) were consistently negative across all provinces but not always significant. This means that improving household access to non-farm opportunities in Miombo forest landscapes could reduce the pressure on forests (Angelsen and Kaimowitz, 1999; Appiah et al., 2009).

In addition, while access to roads and distances to markets (i.e., main roads and village centre) had a different impact on deforestation within regions, access to roads was only associated with high deforestation in the North-Western and Eastern Province. This result suggests that in the early forest transition (North-Western Province) and the late forest transition (Eastern Province) of Zambia, road expansion can potentially exacerbate high deforestation (Barber et al., 2014; Cordero-Sancho and Bergen, 2018). At the same time, we found that increases in walking distance to markets were associated with a reduced likelihood of high deforestation within provinces. Together, these findings mean that households' access to the markets can influence high deforestation in the Miombo landscapes. However, the likelihood of high deforestation can be reduced if settlements (households) are located further away from the markets (see also Babigumira et al., 2014).

Lastly, we found that restriction on access to and use of forest resources is associated with reduced deforestation in the North-Western and the Eastern Province. However, in the Copperbelt Province, restriction on access to and use of forest resources was not significantly associated with high deforestation. On the one hand, this finding implies that restriction regimes could effectively reduce high deforestation in some provinces of Zambia. This reasoning is supported by studies elsewhere that explain the role of forest policy in forest conservation (Blankespoor et al., 2017; Harvey et al., 2010). On the other hand, it suggests that restriction on access to and use of forest resources on its own is not an effective measure in preserving forest integrity. This is because, in some provinces such as the Copperbelt, forest use (i.e., fuelwood and charcoal production) form a major part of household's livelihoods strategy (Table 2A) (see also Kalaba et al. (2014)).

5.3. Spatial distribution of agricultural land-use and deforestation along a forest transition gradient

Based on the conceptual framework that incorporates distances (von Thünen, 1826) and relates crop productivity (returns to a unit of land) to deforestation along a forest transition (Fig. 1), we observed a significant association between crop productivity and deforestation patterns, but the impact of crop productivity greatly varied across distance categories (Table 6) and along the forest transition gradient (Table 5). As such, our results are partly contrary to theoretical expectations. We found that crop productivity does not consistently relate to high deforestation at different distance categories and along the forest transition; rather were significant in different directions (different signs). These findings can be aligned with studies explaining deforestation along the forest transition (Barbier et al., 2010; Khuc et al., 2018; Singh et al., 2017; Wolfersberger et al., 2015), but challenges the view that forest transition can be related systematically to agricultural productivity (Angelsen, 2007; Schielein and Börner, 2018).

In the early transition (North-Western Province), our results indicate a trade-off between commercial crop production and deforestation (Table 5a), but the effects were not significant across distance categories. In the mid-transition (Copperbelt Province), commercial crop production has a similar but significant impact on deforestation in the medium-distance category. These results are supported by studies that ascertain the role of agriculture in the form of crop productivity in reducing deforestation (Mulenga et al., 2017; Ngoma et al., 2019; Wollenberg et al., 2011). This finding indicates that perhaps high crop productivity (i.e., high crop returns on a unit of land) can substitute for forest products extraction in the provinces with the highest proportion of forest cover in Zambia.

Additionally, following Ngoma et al. (2019), Phiri et al. (2019b), in their studies explaining the relationship between crop productivity and deforestation in Zambia, we found a positive and strong significant relationship between cereals crop productivity (subsistence crop production) and deforestation along a forest transition and across distance categories. This finding is contrary to studies that explain high deforestation as associated mainly with commercial crop production in the tropical and subtropical countries (DeFries et al., 2010; Ryan et al., 2017) and along the forest transition (Angelsen, 2007). Our study, however, is at the household level and analysed small-scale crop production. Therefore, what we explored was small-scale commercial production, usually related to improved livelihood aspects. Accordingly, it is important to note that the effects of large-scale output were not captured.

Overall, our results indicate that small-scale commercial production might not be the prominent factor associated with deforestation patterns in the Miombo forest landscapes. Instead, deforestation can be associated with subsistence farming, charcoal and firewood collection. These land uses appear to largely influence household income in Zambia's Miombo landscapes (Tables 2A and 5) (see Handavu et al., 2019; Kazungu et al., 2020). These household activities are usually not related to fixed land-use patches and often happen informally or even illegally. Thus, this might be a hidden spatially relevant land-use factor that is countering the theoretical expectation.

6. Conclusions

Our study contributes to the literature and practice on estimating deforestation and understanding the effects of household-level attributes on deforestation across landscapes and regions (provinces). This work is empirically based on the framework that integrates distance (von Thünen, 1826) and the forest transition (Angelsen, 2007; Mather, 1992). We use remotely sensed data and survey data collected in the Miombo forest landscapes between 2017 and 2019 to compute deforestation across distances from households' homesteads to land-use patches and assess the relationship between household-level attributes, the spatial distribution of agricultural land-use and deforestation across forest landscapes and regions. By applying deforestation models at the regional level, we avoided the occurrence of average causal factors that often occur when deforestation models are used uniformly at the national level (Köthke et al., 2013).

We found that the average annual rate of deforestation varies across the study provinces (forest transition gradient), but trends vary considerably across distance categories, which indicates that the economic-related distance effects (von Thünen) are complementary to the forest transition in the Miombo forest landscapes. This result provides empirical evidence confirming Angelsen (2007). On the one hand, we found systematic trends of decreasing deforestation rates across distance categories from households in the early (North-Western Province) and mid-forest transition regions (Copperbelt Province). On the other hand, we found increasing deforestation rates across distance categories from households in the late-transition area (Eastern Province).

Besides, while we found that household attributes in Miombo forest landscapes were important factors associated with deforestation, the effects of household-level factors on deforestation patterns differ significantly within and across provinces, indicating the importance of regional analysis. In the Copperbelt Province, we note, in particular, that higher education empowers households with the means that can facilitate deforestation. This finding challenges the view that better education can facilitate greater access to livelihood opportunities that could reduce deforestation.

Our results further reveal that land-based attributes, non-farm income and location attributes strongly affected the likelihood of deforestation within provinces, but the effects were in different directions (different signs) and were mixed (strong or weak). Besides, the findings reveal that crop productivity is not consistently linked to high levels of deforestation at different distances and along the forest transition, but rather crop productivity is significant in different directions. However, our study was conducted at the household-level and examined small-scale crop production, indicating complementary livelihood-driven deforestation patterns but not exclusively linked to land-use productivity.

The findings in this study indicate that estimating household areas of influence in agrarian economies is essential for understanding the scale and patterns of deforestation. Consequently, policy intervention should be regional-specific, accounting for production lines, forest transition stages and context. It is important to note that increasing access to non-farm income sources in all regions would increase household income while simultaneously decreasing involvement in household activities that can lead to high deforestation. In addition, our findings seem to suggest that promoting land-use practices that can integrate reforestation and agroforestry while increasing crop production in Copperbelt and the Eastern Province can ensure a reduction in high deforestation. Finally, while access to roads and markets is a prerequisite for broadening provincial-wide involvement in non-farm livelihoods, caution should be observed in the North-Western as the extension of road networks to forested areas could exacerbate high deforestation.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A

Table A1
Generalized odered logit model results of deforestation for the whole sample.

Variables	Marginal effects		
	Deforestation levels		
	Low	Medium	High
Socio-demographic attributes			
Age of household head, years	−0.00296 (0.0111)	0.000157 (0.000593)	0.0028 (0.0105)
Male-headed household, 1 = Yes; 0 = No	−0.0169 (0.0276)	0.00106 (0.00204)	0.0158 (0.0256)
Head of household attained above primary education, 1 = Yes; 0 = No	−0.00701 (0.024)	0.000345 (0.00111)	0.00667 (0.0229)
Household size, Number of members	−0.00158 (0.0104)	0.0000842 (0.000554)	0.0015 (0.00983)
Duration of residence in the village, years	0.00735 (0.0107)	−0.00039 (0.000594)	−0.00696 (0.0101)
Land-based attributes			
Total size of patches of land owned, ha	−0.0294** (0.0149)	0.00156 (0.00103)	0.0278** (0.0142)
Livestock, tropical livestock unit (TLU)	−0.0426*** (0.0124)	0.00227* (0.00122)	0.0404*** (0.0117)
Forest products (unprocessed), ZMW	0.00995 (0.0116)	−0.000529 (0.000657)	−0.00942 (0.011)
Charcoal production, ZMW	−0.113*** (0.0191)	0.00600** (0.00304)	0.107*** (0.0173)
Capture fish, ZMW	0.0490*** (0.0106)	−0.00260** (0.00116)	−0.0464*** (0.0102)
Off-farm income, ZMW	0.0144 (0.00955)	−0.000766 (0.000595)	−0.0136 (0.00906)
Cereals crop production, ZMW/ha	0.0314*** (0.0104)	−0.00167* (0.000859)	−0.0297*** (0.00995)
Vegetable production, ZMW/ha	0.0079 (0.0102)	−0.00042 (0.000576)	−0.00748 (0.00961)
Legumes production, ZMW/ha	0.014 (0.0106)	−0.000743 (0.000649)	−0.0132 (0.01)
Non-land-based attributes			
Non-farm income, ZMW	0.0247** (0.0101)	−0.00131* (0.000763)	−0.0233** (0.00957)
Location attributes			
Household had access to permanent road, 1 = Yes; 0 = No	0.131*** (0.0219)	−0.00676* (0.0036)	−0.124*** (0.0204)
Household distance to main road, walking time (minutes)	0.0830*** (0.0114)	−0.00441** (0.00194)	−0.0786*** (0.0109)
Household distance to the village centre, walking time (minutes)	−0.0172* (0.0103)	0.000912 (0.000602)	0.0163* (0.00985)
Landscape has forest reserve, 1 = Yes; 0 = No	0.232*** (0.0219)	−0.0130* (0.00678)	−0.219*** (0.0196)
Patch of land-use in medium-distance (close is base outcome)	0.121*** (0.0227)	−0.00364 (0.00308)	−0.118*** (0.0231)
Patch of land-use in remote-distance (close is base outcome)	−0.00277 (0.0279)	−0.000293 (0.00298)	0.00306 (0.0309)
Landscape in wet Miombo areas (North-Western & Copperbelt), Yes = 1; 0 Otherwise	−0.324*** (0.0202)	0.0172** (0.00708)	0.307*** (0.0212)
Log-likelihood	−940.72		
Pseudo R^2	0.23		
N	1123		

*** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$. Standard errors in parentheses.
dy/dx for factor levels is the discrete change from the base level.

Appendix B. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.ecolecon.2021.107070.

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10.3. Publication 3

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Article

Household-Level Determinants of Participation in Forest Support Programmes in the Miombo Landscapes, Zambia

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Abstract: The need to protect forest resources from unsustainable, yet rational, human actions has attracted global attention. This is because smallholder dependence on forests can degrade forest resources and cause deforestation. While efforts to understand forest programmes and motivations to protect forests have increased in recent decades, there remains a limited understanding of household factors affecting participation in forest support programmes, especially in the context of high-pressure areas, such as the Miombo woodlands. This study was conducted in the North-Western, Copperbelt and Eastern Province of Zambia. In each province, we selected landscapes consisting of protected and non-protected forest areas. We administered structured interviews to 1123 households and used logistic regression to estimate determinants of participation. We found that better education, landholding size, increased share of forest income, cash crops and non-farm income, and access to forests and markets have a negative impact on participation in forest support programmes. Being located in landscapes with protected areas was positively associated with participation. We suggest that, in order to increase participation, forest programmes should focus on households with low levels of education, limited livelihood opportunities, and poor access to markets. Besides, programmes should provide incentives, including support for farm inputs and at the same time encourage reforestation and agroforestry methods.

Keywords: miombo woodlands; participation; households; opportunity costs and benefits; logistic regression

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1. Introduction

Globally, there is a consensus among scholars and policymakers that forests need to be protected from unsustainable, yet rational, human actions [1–4]. This is of particular concern for tropical and subtropical dry forests because of the continuous dependence on forest resources and forestlands' conversion to agricultural fields [5–7]. As such, efforts to understand forest support (FS) programmes and stakeholders' motivation to protect forest resources have intensified in recent decades [8–11]. However, there remains a limited understanding of the contextual factors affecting household participation in FS programmes [12,13].

FS programmes can include protected areas and collaborative forest management strategies, including community forest management, joint forest management, co-management, and payment for environmental services [14–18]. Collaborative forest management strategies are often developed to empower households to manage their forest resources. It is suggested that by taking care of forests, households' livelihoods will improve and deforestation will reduce [19]. On the other hand, the protected area strategy emphasises strict control to access and allows for sustainable human use [20]. This strategy aims to protect and preserve biological diversity and natural and cultural resources under legal management or other effective means [20]. Lastly, payment for environmental services involves voluntary transactions under agreed rules for the management of natural resources between service users (communities) and service providers [21]. Together, these forest management strategies are considered complementary for achieving biodiversity conservation and improving household livelihoods [22,23]. Hence, FS programmes can be defined as forest management strategies that incorporate local (household) needs and ensure sustainable development while contributing to the reduction of deforestation (see [1,18]).

In most countries, however, FS programmes are often designed to achieve specific outcomes, which can be related either to forest conservation [24] or sustainable use of forest resources (i.e., conservation and rural development) [25,26]. For example, in the high tropical rainforests such as Brazil or Ecuador, FS programme design emphasises species conservation and deforestation reduction [27,28]. In the tropical dry forest areas, such as the Miombo woodlands of Zambia, forest areas are a source of land for rotational fallows and new agricultural fields [7]. Moreover, forest products' extraction is intertwined with most households' livelihood strategies [29,30]. The high forest use and demographic changes can increase pressure on forest resources, which leads to deforestation and forest degradation [5,6,31].

Until recently, FS programme designs in the tropical dry forest areas often emphasised sustainable use of forest resources [1,32]. However, there is a need for programme designs to consider the claim for alternative land uses. FS programmes designs should aim to balance both agriculture and forest livelihood components [33,34]. Therefore, balancing forest management and livelihood improvements can have economic implications on forest programmes and households [8,35]. Despite continued efforts by countries to sign global frameworks (e.g., UNFCCC and REDD+) that guide the design and implementation of FS programmes, it is recognised that many factors can influence households participation in FS programmes [36]. These factors may include institutional arrangements [9,23], socio-demographic factors, economic aspects, and access to forest resources and markets (access factors) [37,38], and have been found to vary across different countries [11,39,40].

Socio-demographic factors such as age, education and household size are especially important because experience and skills development and household size can enhance environmental attitude change and increase labour availability, which can be associated with participation in FS programmes [39–41]. Economic attributes such as landholding size and income source can either motivate or discourage participation if perceived as limiting the use of forest resources [41,42]. Lastly, access factors, including access to forestlands and distances to markets, can either encourage or discourage participation in FS programmes [37,40].

Given the increasing pressure on forest resources in the dry forest areas and Miombo in particular [32,43,44], it becomes crucial to understand household-level factors associated with participation in FS programmes. Despite past interests in understanding the impacts of these contextual factors on forest programmes, there is still a weak understanding of how these factors affect participation in FS programmes in the Miombo area [45,46]. Moreover, in these areas, woodland management and forest uses are highly intertwined with households' livelihood strategies [32,34]. For example, in Zambia, the National Forestry Policy [47] and the Forests Act [48] stipulate multistakeholder co-management and benefits sharing among stakeholders. However, given differences in the rural economy and prevalent heterogeneity among rural households, it becomes essential to understand whether participation in FS programmes results from differences in household attributes or merely by nature of the rural economy [36,39,42]. Failure to understand the impact of these factors on FS programmes may lead to a low level of acceptance of forest programmes in some areas, resulting in a potential failure of the programmes to meet their objectives [45,49].

Past attempts in Zambia to understand FS programmes' success mainly focused on analysing the governance structures that can ensure successful participation [26,46,49]. This is based on the view that a well-functioning governance structure guarantees sustainable outcomes such as improved livelihood outcomes [23,50,51]. However, the designs and the broader policy context guiding FS programmes in Zambia often do not align with the local context in which households operate, which creates confusion on prioritising forest conservation or enhancing livelihood benefits [52,53]. For instance, previous studies reveal that rural households in Zambia highly depend on forests for their livelihoods [29,54,55]. Yet, Zambia's management of forests is still under "old-style" forestry that focuses on the regulatory functions [32]. This has, however, created uncertainty in the design and implementation of most FS programmes.

While some attempts have been made to introduce FS programmes in protected areas (i.e., areas with limited access to and use of forests) and non-protected sites [47,48,56], the majority of FS programmes in Zambia are characterised by deficiencies in design and implementation [49,53]. For example, in their study, Bwalya and Vedeld [45], and Phiri [46] highlights the mismatch between households' livelihood expectations and programme goals, leading to FS programmes' failure to deliver successful outcomes. Despite low acceptance rates and the failure of most forest programmes to achieve sustainable outcomes, previous studies in Zambia have not exhaustively examined how household-level attributes can influence participation in FS programmes [13,57]. Therefore, understanding household-level factors can be a good starting point for prioritising forestry sector policies to increase the effectiveness of FS programmes and contribute to poverty reduction among households in tropical dry forest areas [1,58,59].

Against this backdrop, we assess participation in FS programmes based on household survey data collected in the Miombo area consisting of landscapes with partly restricted access to and use of forest resources (protected areas) and landscapes with non-restricted access to and use of forest resources (non-protected areas). We examine households' socio-demographic aspects, economic attributes and access factors (access to forest and markets) that can affect participation in FS programmes. The quantitative measures of household-level attributes reflect local and contextual factors that can determine participation. As such, we can check the competing hypotheses that affect participation, as described in Section 3.3 (Table 1). The following question guides our study: how do socio-demographic factors, economic attributes, and access to forest resources and markets affect households' participation in FS programmes in the Miombo forest landscapes of Zambia?

2. Theoretical Concept

In tropical and subtropical dry forest areas, forest use and agricultural land use form the most significant sources of household livelihood portfolios [2]. However, due to forest resources and agricultural production's seasonal nature, rural households often have multiple income sources; thus, rural households are recognised to engage mainly in diversified livelihood strategies [60]. These livelihood strategies mainly include forest products extraction, crop production, livestock grazing and off-farm activities [29,61] and are considered to be associated with deforestation and forest degradation [5,6]. As such, efforts to reduce smallholder deforestation and forest degradation can have an economic implication, especially on households that depend on forests and agriculture for livelihoods.

While previous studies agree that livelihood benefits can affect participation differently, households' decisions to adopt specific livelihood strategies are suggested to be influenced by multiple underlying processes and livelihood benefits [38,40]. The decision to participate can depend on the economic costs and benefits of household activities and participation [8,35]. For example, household sizes can reflect household labour allocation to various forest products, leading to increases in households' total income compared to their counterparts with relatively smaller household sizes [62]. Hence, the opportunity cost approach can be used to assess the relationship between underlying household processes, including sources of income, access to forest resources and participation in forest support programmes [8,63].

The costs and benefits depict the trade-offs between benefits to households now and in the future through sustainable forest resources management [8,64]. This can be important in understanding household processes, motivations, and expected benefits from participating in forest support programmes [35,65]. Given that rural households are often involved in many livelihood strategies [60], in the Miombo area it is recognised that forest support programmes should aim at improving rural livelihoods and minimise actions leading to unsustainable use of forests [32,46]. However, the challenge in forest programme design is to balance the attainment of programme objectives, while ensuring the improvement of the benefits that households gain from forest resources [1,57]. Assessing the incentives that motivate participation in forest programmes, requires an inventory of the competing activities and contextual factors, including costs and benefits of livelihood sources that influence household's participation [8,10,38]. This study contributes to understanding the relationship between household-level factors, including economic costs and benefits of forest use and participation in forest support programmes.

3. Material and Methods

3.1. Study Area

This study was conducted in the North-Western, Copperbelt and the Eastern Provinces of Zambia (Figure 1). The study provinces have Miombo vegetation, characterised by trees of the genera *Brachystegia*, *Julbernadia* and *Isoberlinia* [66,67]. These provinces receive annual rainfall ranging from 600 to 1500 mm [67–69]. Additionally, the North-Western Province, Copperbelt and the Eastern Province are further characterised by considerable variation in the forest cover (i.e., the Copperbelt Province = 64.4%, North-Western = 74.5%, and Eastern Province = 17.5%) [70]. Forest management strategies and programmes in these provinces seem to have varying goals aligned with each province's remaining forest cover (Figure A1). For instance, in the Eastern Province, FS programmes are predominantly intended for replenishing soil fertility while increasing forest cover (i.e., reforestation) [71,72]. In the North-Western Province, FS programmes are mainly structured to achieve conservation outcomes (Figure A1).

Hence, following the methods defined by Kazungu [29] and Nansikombi [73], the study selected paired landscapes consisting of landscapes with restricted access to and use of forest resources and non-restricted landscape (i.e., with open access forests). In both areas (i.e., the restricted and non-restricted landscapes), households acknowledged FS programmes' existence (Figure A2). Overall, 12 landscapes consisting of protected and non-protected landscapes were surveyed in the North-Western Province, the Copperbelt and the Eastern Province (Figure 1).

3.2. Sampling and Household Survey

This study drew a random sample from households located in 37 villages across the North-Western Province, Copperbelt, and the Eastern Province of Zambia (Figure 1). In each province, enumerators conversant with the regional dialect and who fluently spoke the local language [74] were recruited and trained in survey data collection. Data were collected through in-person, structured interviews, and validated before being uploaded into the database. Before interviews, respondents were asked for their consent to participate in the research programme (Appendix C). The interviews lasted between one hour and one-and-a-half hours. The methods used for selecting participating households are described in Kazungu [29]. Overall, we interviewed 1200 households; however, a subset of 1123 households is included in the analysis due to missing values and outliers in some variables. The study collected information about household composition, livelihood activities (i.e., forest products, land and non-land activities), land-use trajectories, and forest support programmes.

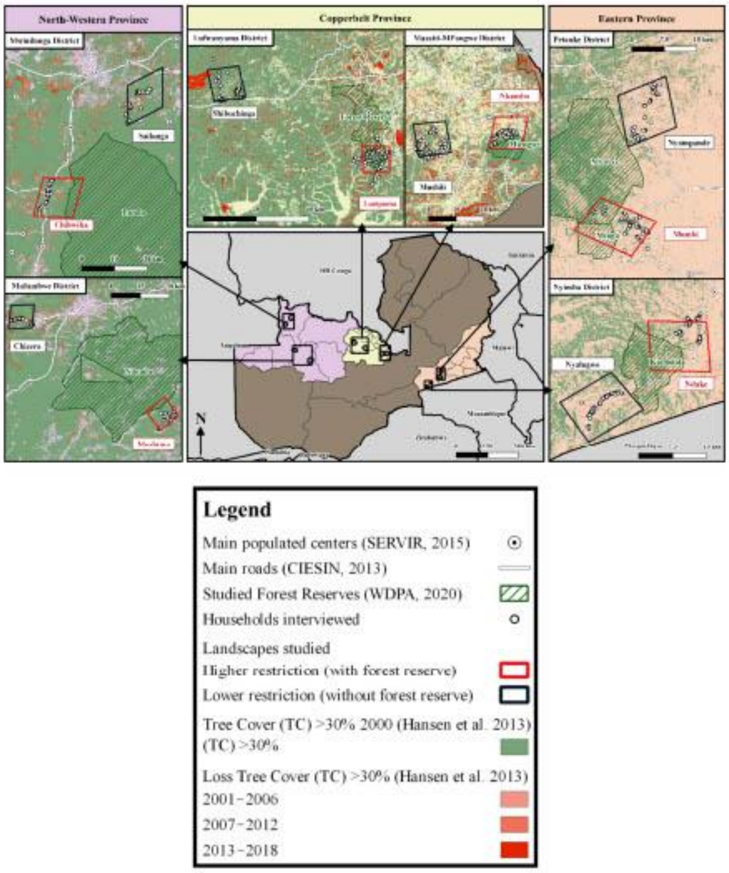

Figure 1. Map of Zambia showing landscapes with protected and non-protected areas in the study provinces of North-Western, Copperbelt and Eastern Province.

This study uses self-reported quantities for own consumption and sold and average village-level market prices to estimate income values. The respondents reported weekly and monthly amounts of different crops, forest products, livestock, and gifts, consumed or sold. The weekly and monthly product amounts were aggregated to give annual income estimates. Income was calculated as net values by subtracting all the costs associated with the production. However, household's labour was not deducted from the income calculation because there was no standard for quantifying own labour in Zambia's rural areas (see also Cavendish [75]).

In order to assess the participation of households in FS programmes, we first sought to understand household awareness of the existence of FS programmes in their communities. Respondents were asked to name all forest programmes that aimed to increase forest cover, preserve forests and improve forest management in their villages (Appendix A). In this study, about 65% of the households were aware of forest programmers' existence. Of the 1123 respondents, 413 households registered and successfully participated in FS programmes (Table 1). Households identified multiple FS programmes that were later categorised into six broad groups: conservation programmes, land rights, advocacy and capacity building, agroforestry programmes, government initiatives, beekeeping programmes and other programmes (name of programme unknown) (Figures A1 and A2).

3.3. Data Analysis

3.3.1. Variable Selection and Research Hypotheses

The purpose of our analysis is to test specific hypotheses and to determine factors that motivate households to participate in FS programmes. Participating in FS programmes in this study means participation through membership, where a household registers and participates in FS programmes (i.e., successfully participated in FS programmes). On the other hand, non-participating households did not participate in programmes even though some had registered with forest support programmes. Therefore, based on the literature on forest programmes, we selected several characteristics for inclusion in the analysis with their expected sign (Table 1). However, it is noteworthy that the means calculated in Table 1 do not, in every case, confirm the expected signs. This study's household-level factors are thus categorised into three broad dimensions: socio-demographic aspects, economic and access factors (Table 1).

In the first dimension, we assess socio-demographic factors such as the age of household head, gender, education level of household head, household size, and duration of residence in the village. In our study areas, the socio-demographic attributes vary between households that participated and those that did not participate in FS programmes (Table 1). The age of the household head provides information about the household head's experience and integration level in group and community activities [76]. This variable has been noted to have contrasting effects on participation. Some studies suggest that as the household head's age increases, the likelihood of participation in forest programmes reduces [42,76]. This view suggests that group activities are time and labour intensive; thus, the elderly members find it challenging to participate. On the other hand, it is recorded that older household heads are more likely to participate in FS programmes because participating in programmes can be perceived to enhance households' livelihood options [41]. We hypothesise that households headed by older heads in our study area are more likely to participate in FS programmes because, in rural areas, members are likely to perceive participation as a means that can provide an additional and alternative source of livelihood.

Regarding gender differences in participation in FS programmes, in our study areas, more than 80% of the households interviewed were male-headed (Table 1). As such, we hypothesise that male-headed households are more likely to positively participate in FS programmes than female-headed households. In rural areas in most developing countries, social inequalities and institutional constraints are more likely to reduce the likelihood for participation among female-headed households [39,77,78].

Education is used to measure environmental attitude, behavioural change, and socio-economic status of households [11,77,79]. Attaining higher education levels can increase the ability of a community member to process information regarding the goals and requirements for participation in FS programmes, thereby increasing households' chances to participate in FS programmes [40,41]. In this study, education levels considerably vary between households that participated in FS programmes and those that did not participate (Table 1). Of the 413 households reported to have participated in FS programmes, 19% had attained above primary education level, while for the households that did not participate about 27% had attained above primary education (Table 1). These suggest that better access to education increases households' opportunities to engage in non-forest activities, thereby enhancing resources conservation [11]. We hypothesise that households that attained above primary education in the Miombo areas are more likely to participate in FS programmes because better-educated households can presumably better understand the value of forests and thus participate in FS programmes.

For household size, studies suggest rural households with large membership are more likely to depend on forest resources to diversify their livelihood portfolios [2,80]. In rural economies, large household size can provide a sufficient labour force that can be deployed in various household activities. The opportunity cost of participation in FS programmes becomes less when household size is large [76]. We hypothesise that households with large size will be positively associated with participation in FS programmes.

Regarding residence in the village, in our study area participating households had resided in the village longer (approx. 18 years) than their counterparts who did not participate (Table 1). Accordingly, we expect that the residence duration will be positively associated with participation. The longer a member stays in the community, the greater their chances of participating in programmes that seek to conserve forests for the future generation [40].

The second dimension reflects a household's dependence on land and forest resources for generating income. These factors are designated as economic factors (Table 1) and are expected to have mixed effects on participation (Table 1). Hence, households that engage in crop production and subsistence forest activities are likely to view FS programmes as opportunities to diversify or complement their income portfolios [38,42,81]. Thus, we hypothesise that higher shares of crop incomes (i.e., cash crop and subsistence income) and forest subsistence income are more likely to increase the probability of participation in FS programmes. On the other hand, we expect that households engaged in prohibited activities, such as charcoal production [48,82], are likely to view FS programmes to restrict their charcoal production, thereby increasing the opportunity costs associated with participation. As such, we expect that higher shares from forest income are more likely to reduce the likelihood of participation in FS programmes.

Although the share of capture fish income, off-farm and non-farm incomes (i.e., non-farm operations) in households livelihood portfolios is low (Table 1), non-farm operations are often considered to attract high wages and incomes [40]. Besides, these non-farm operations are often considered labour-intensive; thus, it is likely that the opportunity costs associated with these activities can be higher in rural areas [83]. We hypothesise that higher shares of non-farm incomes (operations) are more likely to reduce the likelihood of participation in FS programmes.

In our study area, access to credit was associated with less participation (Table 1). Of the 413 households participating in the FS programmes, only 33% had access to credit. In rural areas, access to credit facilities can provide the means to increase production and diversify sources of income, thereby increasing participation in FS programmes (see also Coulibaly-Lingani, Savadogo [39]). We expect that access to credit will more likely increase the probability for participation in FS programmes. This is because, in most rural areas of Zambia, credit facilities are limited [84]. Yet, most households are engaged in multiple production activities that require capital [85].

Landholdings and livestock ownership represent important assets held by households [79]. These assets can provide the means for complementary livelihood strategies to rural households [2]. We expect that households with large land size and livestock ownership are more likely to spend their time in land use management and livestock and, therefore, less likely to participate in FS programmes [40].

The third dimension are the factors that reflect access to markets and forest resources (Table 1). In this analysis, access to markets is represented by access and distances that household walked to the main road. About half (48%) of the households that participated in FS programmes had access to main roads and walked a shorter distance (about half an hour) compared to their counterparts that did not participate (Table 1). In Zambia's rural areas, just like elsewhere [40], forests and agricultural produce are mainly sold by the roadside to the travelling public and intermediary traders. Therefore, access to main roads and distances are important for rural households as they represent access to markets [86]. The lack of access to main roads or longer distance walked increases the transportation costs associated with forest products. This affects the quantities collected and consumed [87], which reduces the incentives among households to engage in forest-related issues. Hence, we expect a negative relationship between access to the main road and distances to main roads with participation in FS programmes.

Table 1. Characteristics of non-participating and participating households in FS programmes in the study area.

Variable Definition	Unit	Non-Participants (n = 710)	Participants (n = 413)	The Expected Sign of the Impact on Participation
		Mean (SD)		
Socio-demographic factors				
Age of head of household	Years	44.1 (15.0)	46.4 (13.8)	+
Male-headed household	%	82.5	81.4	+
Head of household attained above primary education	%	26.6	19.1	+
Household size	AEU [a]	4.6 (1.9)	4.8 (2.0)	+
Duration of residence in the village	Years	15.2 (14.1)	18.1 (15.7)	+
Economic factors				
Landholding size	Hectare (Ha)	3.5 (6.2)	2.9 (4.1)	-
Access to credit	%	38.3	32.7	+
Livestock ownership	TLU [b]	0.9 (1.7)	1.2 (2.0)	-
Share of livestock income	%	8.1	9.6	+
Share of forest income-subsistence (unprocessed products)	%	27.2	27.1	+
Share of charcoal income (processed product)	%	21.8	25.2	-
Share of crop income-subsistence	%	14.6	15.9	+
Share of crop income-cash	%	21.6	16.5	+
Share of off-farm income	%	2.1	2.3	-
Share of capture fish income	%	0.5	0.2	-
Share of non-farm income	%	4.1	3.3	-
Access factors				
Access to permanent roads	%	41.1	48.2	-
Walking distance from household to the main road	Minutes	71.0 (121.4)	27.5 (57.9)	-
Walking distance from household to exclusively used forestland	km	2.5 (1.9)	2.5 (2.2)	-
Walking distance from household to public forestland	km	2.6 (1.8)	1.7 (1.6)	-
Households in landscapes that have a restriction (protected areas)	%	45.5	56.2	+

Standard deviation (SD) in parentheses. [a] Adult equivalent units (AEU) as defined by Dokken and Angelsen [88]. [b] TLU—tropical livestock unit. N= 1123. *Source:* Own computation from household surveys (2017–2019).

As used in this analysis, distance to forestlands reflects costs and time associated with harvesting forest resources (Table 1). In this study, households that participated in FS programmes stayed closer to public forestland than their counterparts that did not participate. Therefore, we hypothesise that increasing households' distances from forestlands is more likely to reduce the probability of participation in FS programmes [37].

Lastly, households located in landscapes with restricted access to and use of forest resources (protected areas) are expected to participate more in FS programmes than their counterparts found in landscapes without restriction. This can presumably be due to the high level of awareness among households in landscapes with protected areas. However, it can also be because of increased benefits derived from being closer to protected areas such as access to the edge of parklands for crop cultivation [81], or increased illegal harvesting of forests resources [29,37]. Consequently, we expect that being located in landscapes with protected areas will be positively associated with the likelihood of participation in FS programmes.

3.3.2. Statistical Analysis

Our analysis included 1,123 households surveyed in the study area. The dependent variable is participation in FS programmes, which is a binary outcome that contains one (1) for households that registered and successfully participated in FS programmes, and zero (0) for those not participating (Table 1). Being a binary outcome implies that ordinary least squares (OLS) regression cannot be appropriate in modelling factors affecting households' participation [89]. Such outcome, however, is best explained with binary choice models [90]; in this study, we use a logistic regression model. The logistic model was chosen because it provides precise, meaningful estimates of the impact of the explanatory variables (Table 1) on an observed set of data (dependent variable) [91].

The descriptive variables presented in Table 1 were statistically diagnosed, which resulted in the exclusion of four variables with a correlation coefficient greater than 0.3 ($r > 0.3$). Notably, the variables excluded were residence duration, correlated with age; access to credit, correlated with charcoal income; tropical livestock unit (TLU), correlated with livestock income; and crop subsistence income, correlated with charcoal income. Additionally, cash crop income was correlated with forest subsistence income ($r = 0.4$). These variables were still retained because there was a substantial difference in cash crop incomes and subsistence forest income among households that participated and those who did not participate in FS programmes (Table 1). Furthermore, by using backward elimination, we excluded variables with $p > 0.5$, which included off-farm income, access to permanent road, and distance to exclusively used forestlands.

To interpret the model outcome, we estimate the coefficients (i.e., coefficients correspond to the log of odds ratio), and the result is interpreted by estimating the marginal changes. The marginal effects for the continuous variables measure the instantaneous rates of change. The marginal effects are interpreted as discrete changes for the dummy variables, which means how the predicted probability changes as the binary independent variable changes from 0 to 1 [92].

Thus, the binary outcome for participation in FS programmes takes the form:

$$\begin{aligned} Y_i = 1 \text{ if } Y^* &= fi_1 X_i + ''_i > 0 \\ &= 0 \text{ if otherwise} \end{aligned} \quad (1)$$

where Y is the observed dependent variable (Participation), and Y^* is the unobserved variable (latent), β is a vector of unknown parameters (coefficients) to be estimated. X is the vector of explanatory variables, including the age of household head, gender, education, household size, landholding size, incomes (crop, forest, non-farm incomes), distance to forestland, markets and restriction to access and use of forest resources (Table 1). The term ε is the error expressing observations' deviations from the conditional mean. i represents the observations ($i = 1, 2, 3 \ldots$). For clarity, the subscript i is suppressed.

Thus, the logit model shall be as follows [91,93]:

$$P(x) = \frac{e^{\beta_1 X}}{1 + e^{\beta_1 X}} \quad (2)$$

where $P(x)$ represents the conditional probability of $Y_i = 1$ given x_i, (i.e., $P(Y_i = 1 | x_i)$).

Thus, from Equation (1), the dependent variable (Y) will be; $Y = P(x) + \varepsilon$.

Accordingly, if $Y = 1$, then $\varepsilon = 1 - P(x)$ with a probability of $P(x)$.

If $Y = 0$, then $\varepsilon = -P(x)$ with a probability of $[1 - P(x)]$.

Hence, the conditional distribution of the outcome variable follows a binomial distribution with a mean of zero and variance equal to $P(x)[1 - P(x)]$.

To estimate the logistic regression, we apply the maximum likelihood (ML) method. The ML yield values for unknown parameters that maximise the probability of obtaining the observed set of data. Therefore, we maximise the log-likelihood function to estimate the probability of the observed data, as shown in Equation (3):

$$\begin{aligned}\log(\mathrm{L}(\mathrm{fi}) &= \log\prod_{i=1}^{N}\left[\mathrm{P}(\mathrm{x})^{y_i}\,(1-\mathrm{P}(\mathrm{x_i}))^{1-y_i}\right] \\ &= \sum_{i=1}^{N} y_i \log(\mathrm{P}(\mathrm{x_i})) + (1-y_i)\log(1-\mathrm{P}(\mathrm{x_i})).\end{aligned} \quad (3)$$

Thus, the parameter estimates obtained are used to find the marginal impact of the change of each explanatory variable (x_i) when the probability of observing $Y_i = 1$ [94].

4. Results

The logistic regression results that were estimated to determine the factors that influence households' participation in FS programmes are shown in Table 2. The McFadden R^2 and chi-square (X^2) indicates that our full model predicts significantly better or more accurately than the null model [95,96]. This suggests that household-level factors (i.e., first column of Table 2) chosen in this study statistically explain variations in participation among households. Consequently, the second column in Table 2 includes the coefficients and shows the effects of explanatory variables on the outcome variable (participation). The third column shows the magnitude of change (marginal effects) of the coefficients.

Generally, our results show that socio-demographic attributes were less prominent factors explaining participation in FS programmes; instead, participation can be explained mainly by economic and access factors (Table 2). However, surprisingly, we note that the education variable has a negative sign and is significant ($p < 0.05$). The marginal effect is −0.074, which implies that a household whose head attained above primary education is 7.4 percentage points less likely to participate in FS programmes than a household whose head did not attain above primary level education, holding all other factors constant. This result is supported by descriptive data (Table 1). Younger and more educated households' heads (about 27%) chose not to participate in FS programmes than their counterparts participating in FS programmes.

With regard to economic factors, the results show that the effect of household economic attributes on participation in FS programmes was negative and mainly significant at the 0.01 alpha level. Although some economic variables confirmed our hypotheses, others were surprising (Table 2). As expected, we found that increases in landholding size (ha) reduces the probability of participation in FS programmes, although only significant at 0.1 level (Table 2). The predicted probability is −0.0068, which means that an additional one-hectare increase in landholdings reduces the likelihood of participation by 0.68 percentage points, keeping all other factors constant.

We note with surprise that a unit increase in the share of forest subsistence income decreases the probability for participation by 0.4 percentage points, holding all other factors constant. At the same time, though expected, a unit increase in the share of charcoal income reduced the probability for participation by 0.25 percentage points, holding all factors constant (Table 2).

Furthermore, we found surprisingly that a unit increase in the share of cash crops income reduces the likelihood of participation by 0.5 percentage points, keeping all other factors constant (Table 2). This finding suggests that households with a relatively higher share of crop incomes (Table A1) have a lesser interest in participation in FS programmes.

Other income variables, including capture fish income and non-farm income, had the expected negative signs and were highly significant ($p < 0.01$) (Table 2). Our results indicate that for every unit increase in the share of capture fish income, the probability for participation decreases by 5.8 percentage points, keeping all other factors constant. For non-farm incomes, we found that a unit increase in the share of non-farm income reduces the probability of participation by 0.42 percentage points, holding all other factors constant. Altogether, these findings indicate that increases in the proportion of non-forest-based income (i.e., crop income, fish catch and non-farm income) are more likely to have adverse effects on participation than increases in the proportion of forest income (Table 2).

Table 2. Logistic regression results of determinants of participation in Forest Support (FS) programmes.

Variables	Coefficients	Marginal Effect (dy/dx)
Socio-demographic factors		
Age of head of household (Years)	0.006 (0.005)	0.001 (0.001)
Male-headed household (Yes = 1; No = 0)	0.236 (0.190)	0.052 (0.041)
Household head attained above primary education (Yes = 1; No = 0)	−0.339 ** (0.169)	−0.074 (0.037)
Household size (Adult equivalent units - AEU)	0.035 (0.037)	0.008 (0.008)
Economic factors		
Land holding size (ha)	−0.031 * (0.016)	−0.007 (0.003)
Livestock income (%)	-5.80×10^{-5} (4.97×10^{-5})	-1.27×10^{-5} (1.09×10^{-5})
Subsistence forest income (unprocessed forest products) (%)	−0.018 *** (0.005)	−0.004 (0.001)
Charcoal income (processed forest products) (%)	−0.012 *** (0.004)	−0.003 (0.001)
Cash crop income (%)	−0.023 *** (0.005)	−0.005 (0.001)
Capture fish income (%)	−0.264 *** (0.065)	−0.058 (0.014)
Non-farm income (%)	−0.019 *** (0.007)	−0.004 (0.001)
Access factors		
Walking distance from household to main road (minutes)	−0.004 *** (0.001)	−0.001 (0.000)
Walking distance from household to public forestland (km)	−0.310 *** (0.051)	−0.068 (0.011)
Household in landscapes with protected forest area (Yes = 1; No = 0)	0.620 *** (0.141)	0.136 (0.031)
Constant	0.878 ** (0.435)	
LR X^2 (14)	197.56	
Prob> X^2	0.000	
McFadden's R^2	0.13	
Log-likelihood	−639.88	
Observations	1123	1123

*** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$. Standard errors in parentheses.

The access factors included in the analysis are distance to main roads, forestlands and household's location (i.e., in protected forest areas) (Table 2). Distance variables (i.e., distance to the road and forestland) have the expected negative signs and are statistically significant (i.e., $p < 0.01$) (Table 2). Although the distance variables exhibit similar signs, the magnitude of their impact on participation substantially varies (Table 2). An increase in the walking time to the main road decreases the probability for participation by 0.08 percentage points, holding all other factors constant. On the other hand, increases in the walking distance to the forestlands decreases the probability for participation by 6.8 percentage points, holding all other factors constant (Table 2). This result is supported by the descriptive findings in Table 1, which shows substantial variations in distances to the markets and forestlands in the study area. Households participating in FS programmes walked averagely shorter distances (about half an hour) to the markets than their counterparts that did not participate (Table 1).

The variable for access to and using forest resources (i.e., landscape with protected forest areas) has the expected positive sign and is strongly significant. The marginal effect is 0.136 for households in landscapes with protected forest areas (Table 2). This implies that the likelihood of participation in FS programmes for households in landscapes without protected forest areas is 13.6% lower than households in landscapes with protected forest areas, holding all other factors constant.

5. Discussion

In tropical dry forest areas, forestlands and woodlands support millions of people living close to and within the forest landscapes [2,32,97]. As such, households' actions can lead to unsustainable forest resource use [6]. In recent decades, there has been a growing urge to understand contextual factors that influence households' decision to participate in forest support programmes [1,10,26,49]. This is because household-level attributes are highly heterogeneous in rural areas and, therefore, influence participation in FS programmes differently [38,42]. Since rural households are often suggested to engage in diversified livelihood strategies [60], the costs and benefits associated with different livelihood choices may influence household decisions to participate in FS programmes [8,35,65]. However, there is a weak understanding of the strength and the relationships between household-level factors, including livelihood choices, and participation in FS programmes in high-pressure areas such as the Miombo woodlands [45,57]. Using household data from the Miombo landscapes of Zambia, our study analyses household-level factors affecting participation in FS programmes.

Our results indicate that socio-demographic factors, economic attributes, and access factors in Zambia's Miombo landscapes do not foster or improve participation in FS programmes. Instead, findings demonstrate that increased economic benefits among households and access to forestlands are likely to reduce participation incentives. For example, once the household's landholding increases, the likelihood that they will participate in FS programmes decreases. This can be true for most rural households in Zambia, given that livelihoods are mainly from land-based activities [56,98]. This finding indicates that households with more agricultural land for cultivation have less incentive to participate in FS programmes than their counterparts with smaller landholdings [63]. This result means that dependencies on forest resources are linked to lack of access to other livelihood sources [40,88]. This result suggests that, to increase participation among households, FS programmes should target resource-poor households as long as participating in FS programmes can enhance forest preservation and improve the economic status of households. The ten significant variables in the model provide a better explanation of these results' implications for research and practice.

Our results show that households' socio-demographic attributes, economic attributes, and access factors considerably vary between households that participated in FS programmes and those that did not participate (Table 1). With respect to household-level factors that influence participation in FS programmes (Table 2), we found that the socio-demographic attributes of households are not generally important factors, except for the educational variable. Households that attained above primary education had lesser incentives to participate in FS programmes. This outcome is surprising and therefore has important implications for practice. In our study area (Table 1), most household heads that attained above primary education level chose not to participate in FS programmes. The finding suggests that better-educated households have broader livelihood opportunities and are therefore less interested in forest-related issues, as was also found in Uganda's rural areas, particularly among younger household heads [81], and in Ghana [99]. This finding implies that, in order to increase participation in the Miombo areas of Zambia, FS programmes should focus on reaching out to household heads with low educational levels (i.e., below primary school). This can enhance households' understanding of the value of forest resources and their socio-economic status [11].

Previous studies highlighting forest resources' contribution to rural livelihoods suggest that forest resources provide supporting roles to many rural households, including seasonal gap filling and safety functions [59,100]. While the share of forest income (i.e., subsistence and cash income) in total household income is highest in our study landscapes (Table A1), we found that higher shares of forest income adversely affected participation. In part, our results indicate that forest-based livelihoods do not just provide gap-filling and safety roles, but form part of the household's livelihood strategies [29].

Secondly, this finding implies that increased dependence on forest resources for subsistence and cash income is likely to jeopardise participation because households may perceive FS programmes as restrictive to their extractive tendencies [40]. Additionally, the cash gains from charcoal production and subsistence contribution of forest products appear to suggest a higher opportunity cost associated with FS programmes for forest livelihoods [101]. Accordingly, participation in FS programmes becomes a secondary activity with lesser gains [45,46].

Other important sources of income analysed in our study include cash crop, capture fish and non-farm income. These non-forest-based incomes also have a negative and statistically significant relationship with FS programme participation. For cash crop income, particularly, the results were surprising; in part, this could be because the opportunity cost of crop production might have been higher in our study areas [102]. As such, the pursuit of income (economic concerns) becomes more of a household's priority than participating in forest programmes. Additionally, we found that higher shares of capture fish and non-farm incomes were associated with reduced participation in FS programmes. This is likely to be true because the opportunity costs for non-farm operations and fish capture in rural areas are often high [40,83]. However, the low levels of capture fish income and non-farm income in our analysis (Table A1) do not imply that income from these sources' is lacking. Instead, our finding demonstrates that not all households had the opportunity to derive these incomes.

On the one hand, these results show that, when non-forest-based activities become more profitable, participation in FS programmes, on the other hand, becomes less attractive among rural households [103]. This implies that FS programmes would have to provide better incentives to attract households to participate in forest-related activities. Incentives can promote farming and intensify crop production while encouraging households to engage in forestry issues [101,102]. Such incentives may include the provision of specific farm support to households (i.e., provision of inputs) [104,105], off-farm activities and reforestation efforts [106,107].

Access factors analysed in this study include distances to main roads and forestlands. Previous studies have highlighted that access to forest areas and markets for forest products are key elements that affect rural households' participation in FS programmes [40,87]. In Zambia, just like in other countries in the region, forest products are mainly sold by the roadsides to the travelling public. Therefore, distances to the forestland and the main roads signify ease of access to the production areas and markets, respectively [4,86]. These variables in our study had the expected negative signs, which suggest that, if walking distances to the forestlands and markets increases, participation in FS programmes is likely to reduce.

However, we note that increases in distances to the forestlands have a relatively stronger effect than increases in distances to the markets. On the one hand, this result implies that distances to the production areas are of greater concern to rural households than distances to the markets. On the other hand, the result means that households that stayed further away from the forestlands have less interest in forest-related issues [37,87]. Consequently, these findings suggest that, in order to stimulate participation in FS programmes in the Miombo areas, the FS programmes should focus on households that are located closer to forest resources as these households are more likely to participate. FS programmes may not be relevant to households living further away from the forests because such households that stay further away from the forest areas are more likely to be engaged in non-forest-related activities [37,40].

Lastly, our results demonstrate that in landscapes without protected forest areas (non-restricted access to and use of forest resources) households were less likely to participate than their counterparts in landscapes with protected areas. This contrasting outcome could be possible because, in the Miombo area, households' extractive tendencies have been recorded to be higher in landscapes with protected areas [29]. Therefore, it is likely that forest-dependent livelihoods may be possible because of the illegal extraction of forest resources [47,48]. Accordingly, our findings show that greater environmental awareness (Figure A2) and increased direct benefits from forest resources could explain strong participation in protected areas. This could be true because, as a result of forest support programmes, households could be afraid of potentially more control measures [47,108].

6. Conclusions and Policy Implications

This study examined the impact of household-level factors on participation in forest support (FS) programmes in high-pressure areas such as the Miombo woodlands. In the Miombo area, forest management is integrated with a large population of people whose livelihoods are intertwined with forest use. Moreover, households are the de facto managers of forest resources, whose decisions to participate depend on the economic costs and benefits of participation in forest programmes. Taking this into context, we used the economic dimension of costs and benefits to explain how household-level factors affect participation in FS programmes in the Miombo landscapes of Zambia.

We found that households' socio-demographic attributes were not significant factors determining participation, except for the educational variable that was negative and significant. Economic attributes and access factors were largely significant and negatively associated with participation in FS programmes. In particular, we found that attaining above primary education level, large landholding, increased shares of forest income, cash crops, capture fish and non-farm income, and access to forests and markets were negative and significantly associated with participation in FS programmes, while being in landscapes with protected areas was positive and significantly associated with participation in FS programmes.

The finding regarding education suggests that better-educated households appear to have broader livelihood opportunities and are, therefore, less interested in forest-related issues.

Regarding economic attributes, our results demonstrate that dependencies on forest resources are linked to lack of access to other livelihood sources. This finding suggests that in order to increase participation among households, FS programmes should target resource-poor households as long as participating in FS programmes can enhance forest preservation and improve households' economic status.

Finally, to encourage more households to participate, the FS programmes should seek to provide incentives, such as farm input support and access to off-farm activities, and promote measures to increase the availability of forest resources, such as reforestation and agroforestry (e.g., adopting fast-growing trees). We recommend that future studies that analyze factors influencing participation in FS programmes should focus on understanding livelihood typologies between households that attained better education (above primary school) and their counterparts with no education or with lower educational levels (below primary school). As such, researchers and policymakers will be able to understand whether better education improves environmental attitudes and livelihoods, while at the same time enhancing forest conservation.

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Institutional Review Board Statement: The study was conducted according to the guidelines of the Declaration of Helsinki, and approved by the Thünen Institute Ombudsman.

Informed Consent Statement: Informed consent was obtained from all subjects in-volved in the study (Appendix C).

Data Availability Statement: The data presented in this study are available on request from the Thünen Institute of International Forestry and Forest Economics. The data are not publicly available due to institutional policies on data management and personal privacy.

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Conflicts of Interest: The authors declare no conflict of interest.

Appendix A

Forest Support (FS) Programmes in the Miombo Landscapes of Zambia

Forest support programmes have been defined as any forest support programme that provides any payments or benefits to households or communities under mutually accepted conditions to support reforestation and forest-based activities to increase or maintain forest cover in the study area. As a result, these programmes were categorised into six groups, as shown in Figures A1 and A2.

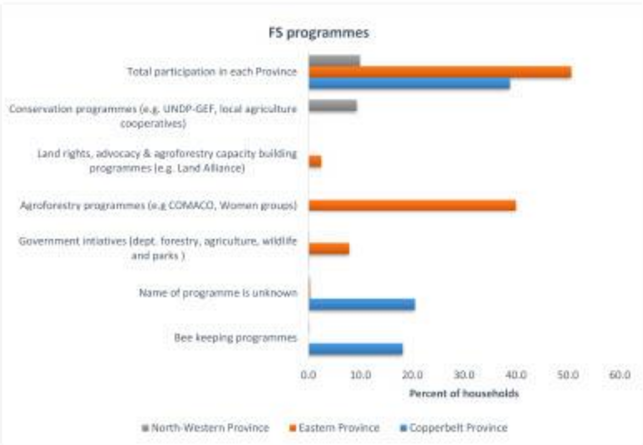

Figure A1. Households reporting FS programmes in the study areas of the North-Western Province, Eastern Province and Copperbelt Province. *Source:* Own computation from household survey 2017–2019.

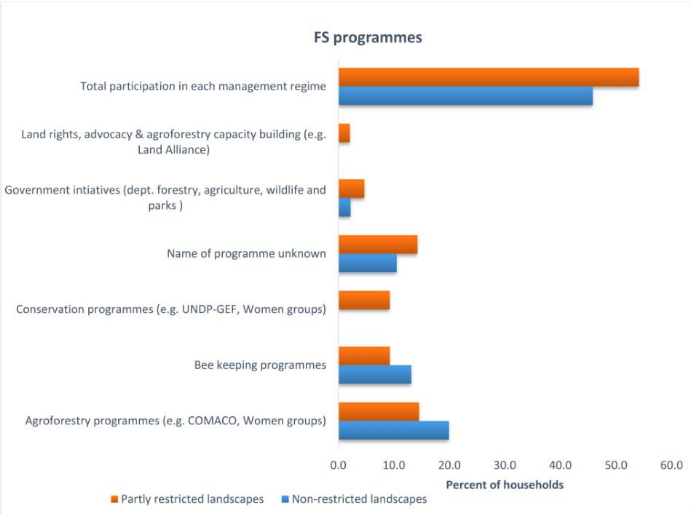

Figure A2. Households reporting FS programmes in restricted landscapes (partly restricted) and non-restricted landscapes in the study area. *Source:* Own computation from household survey 2017–2019.

Appendix B

Table A1. Absolute household income in the study area.

Source of Income	Mean [a] (SD)	Share of the Sample (%)
Forest subsistence income (unprocessed products)	2630.7 (2677.2)	27.1 (15.8)
Charcoal income (processed forest product)	2224.0 (6690.9)	22.9 (39.4)
Crop income, subsistence	1457.5 (1482.9)	15.0 (8.7)
Crop income, cash	1928.5 (3237.7)	19.9 (19.1)
Livestock income	834.1 (1556.1)	8.6 (9.2)
Capture fish income	37.2 (114.1)	0.4 (0.7)
Off-farm income	211.5 (425.6)	2.2 (2.5)
Non-farm income	374.2 (806.9)	3.9 (4.8)
Total household income	9697.7 (9770.2)	100

[a] Income is calculated as net values in Zambian kwacha (ZMW). At the time of data collection (2017–2019), 1 USD = 10.13 ZMW [109]. Standard Deviation (SD) in parentheses.

Appendix C

In the first page of the household questionnaire, the following words were read to the respondent:

We are conducting a survey about how people in your village use the land and the role that forests play for their livelihoods. This research aims to understand how forest management can be improved and benefit the local people. This study is conducted in several villages in this province and other parts of the country. The data will be exclusively used for scientific purposes, published in scientific publications, and presented at national, regional, or local workshops at the end of the research. You will benefit from the knowledge gained through the discussion.

Your participation in this survey is voluntary. If you do not want to participate or answer some questions, you can say it without any problem. If you feel uncomfortable at some point and do not want to continue, please let me know.

Your response is anonymous and confidential; no one in the community will know your answers. We also have no relationship with the government authorities, so your answers will not be shared.

If my question is not clear or if you want any further explanation, please feel free to ask.

Your household has been randomly selected to answer some questions about this topic, and we would like to know if it would be possible for you to answer a survey, which lasts around 1 h? Yes ____ No ___

If the answer is no, say thank you and proceed with the next selected household.

Before we start with the questions, I would like to confirm with you:

Do you give your consent to continue the survey? _____Y/N___

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