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Significant decline in lymphatic filariasis associated with nationwide scale-up of insecticide-treated nets in Zambia

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ABSTRACT

Lymphatic filariasis (LF) is a mosquito-borne disease, broadly endemic in Zambia, and is targeted for elimination by mass drug administration (MDA) of albendazole and diethylcarbamazine citrate (DEC) to at-risk populations. Anopheline mosquitoes are primary vectors of LF in Africa, and it is possible that the significant scale-up of malaria vector control over the past decade may have also impacted LF transmission, and contributed to a decrease in prevalence in Zambia. We therefore aimed to examine the putative association between decreasing LF prevalence and increasing coverage of insecticide-treated mosquito nets (ITNs) for malaria vector control, by comparing LF mapping data collected between 2003–2005 and 2009–2011 to LF sentinel site prevalence data collected between 2012 and 2014, before any anti-LF MDA was started. The coverage of ITNs for malaria was quantified and compared for each site in relation to the dynamics of LF. We found a significant decrease in LF prevalence from the years 2003–2005 (11.5% CI_{95} 6.6; 16.4) to 2012–2014 (0.6% CI_{95} 0.03; 1.1); at the same time, there was a significant scale-up of ITNs across the country from 0.2% (CI_{95} 0.0; 0.3) to 76.1% (CI_{95} 71.4; 80.7) respectively. The creation and comparison of two linear models demonstrated that the geographical and temporal variation in ITN coverage was a better predictor of LF prevalence than year alone. Whilst a causal relationship between LF prevalence and ITN coverage cannot be proved, we propose that the scale-up of ITNs has helped to control *Anopheles* mosquito populations, which have in turn impacted on LF transmission significantly before the scale-up of MDA. This putative synergy with vector control has helped to put Zambia on track to meet national and global goals of LF elimination by 2020.

1. Introduction

Lymphatic filariasis (LF) is a mosquito-borne disease, which is widely endemic in Zambia. Overall prevalence rates were estimated at 7.4% in 2011 from > 10,000 sampled individuals across 108 sites in all regions of the country by rapid circulating filarial antigen (CFA; a marker of the *Wuchereria bancrofti* adult worm infection) BinaxNOW Filariasis immunochromatographic test (ICT) card (Mwase et al., 2014). The initial mapping started in 2003 and 2005 at 42 sites across 14 districts thought to be endemic for LF.

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The prevalence ranged from 0% to 53.9% with the highest found in Lusaka and Western Provinces. Mapping in the remaining 58 districts was conducted at 65 sites in 2009 and 2010, with one site in early 2011. The prevalence ranged from 0% to 20.8% with the highest found in Luapula and Southern Provinces. This endemicity data helped the National LF Programme plan its elimination strategy with an estimated 11 million people requiring treatment. However, the scale-up of programmatic activities was slow to start in Zambia, as unlike many countries in Africa, it did not benefit from the African Programme for Onchocerciasis Control (APOC) that distributed free ivermectin to countries through the established and well trained community drug distributor (CDD) networks (World Health Organization (WHO), 2011).

The Global Programme to Eliminate Lymphatic Filariasis (GPELF) aims to eliminate LF by 2020 by interrupting LF transmission through mass drug administration (MDA) and controlling morbidity (WHO, 2010). In Zambia, as onchocerciasis is not endemic, the use of the drug combination of diethylcarbamazine citrate (DEC) and albendazole for MDA activities is recommended. Albendazole has long been donated to all country LF Programmes from GlaxoSmithKline (GSK), however, DEC had only recently become available for Zambia as a donated drug by Eisai Co., Ltd. (WHO, 2016a). In 2012 and 2014, Zambia conducted a national baseline sentinel site survey across 40 selected sites prior to the start of implementation activities so that impact could be measured over time. In 2015, Zambia successfully scaled up MDA to reach full geographical coverage with very high population compliance rates as part of its strategy to interrupt transmission, making it the largest and most successful distribution of DEC for LF in Africa in history (WHO, 2016a, 2016b).

LF is transmitted by certain anopheline species and the precise incrimination of those species in Zambia associated with transmission is limited. However, in many regions in Africa the LF *Anopheles* vectors are the same, or similar, to those of malaria, which are found across all regions of Zambia at varying distributions and species compositions (Wiebe et al., 2017; Coleman et al., 2017). For example, *Anopheles funestus* and *An. gambiae* are the predominant species in the wetter Eastern, Luapula, Northern and Lusaka provinces while *An. arabiensis* is more dominant in the drier southern region (Masaninga et al., 2013; Chanda et al., 2011; Kamuliwo et al., 2013). A study conducted in Luangwa district in 2011, associated *An. funestus* and *An. gambiae* with LF transmission, however, transmission was not directly confirmed (Shawa et al., 2013). Overall LF prevalence was found to be low (8.6%) and indicated a marked decline from prevalence measured in 2003 (33.3%) (Mwase et al., 2014), which the authors attribute to the concurrent scale up of vector control in the area.

Zambia's achievements in scaling-up interventions are distinctive as it has made tremendous strides over the past decade with very high coverage of vector control for malaria (Chanda et al., 2013). In line with the global trends to improve efforts in malaria control Zambia has put in measures to mitigate malaria transmission including vector control using insecticide-treated mosquito nets (ITN) (Chanda et al., 2012), which are distributed at antenatal and child clinics, equity programme and community mass distributions had reached over 60% at household level in 2008 with the aim of attaining 100% coverage (Chanda et al., 2011). Between 2010 and 2012 over 7 million new long-lasting insecticidal nets (LLINs) were delivered with up to 94% of the population potentially protected from malaria infection. The 2013–2014 Demographic and Health Survey (DHS) reported that around seven in 10 households (68%) owned an ITN, with Southern (79.5%), Eastern (77.1%) and Western (76.5%) Provinces reporting the highest provincial ITN coverage.

The aim of this study was to examine the putative association between LF prevalence and the nationwide scale up of ITNs; specifically, it compared the changes in LF prevalence between the prevalence mapping conducted between 2003 and 2011 and the baseline sentinel site mapping conducted prior to MDA in 2012 and 2014, and the coverage rates of ITNs during the corresponding periods.

2. Methods

2.1. LF prevalence patterns from 2003 to 2014

Endemicity mapping 2003–2011: Initial information on the geographical distribution of LF was based on two phases of mapping surveys conducted across Zambia by the Ministry of Health (MoH) Lymphatic Filariasis Control Programme (2003–2005) and the Programme for Integrated Control of Neglected Tropical Diseases (2009–2011). Community prevalence information was based on data collected from 10,193 individuals from 108 survey sites (Mwase et al., 2014), with the majority of data collected between 2003 and 2010, and only one site in early 2011. These surveys were conducted in accordance with the standard guidelines from the World Health Organization (WHO, 2000), which included adult individuals ($>$ 15 years of age) tested for the presence of CFA from finger-prick blood using the rapid BinaxNOW ICT card. The ICT card was read after 10 min as per manufacture instructions to avoid the possibility of false-positives if the tests are read too late. Details of the survey, methodology and locations have been described previously (Mwase et al., 2014).

Baseline sentinel site surveys 2012–2014: Prior to the implementation of MDA for the elimination of LF, baseline sentinel site surveys were conducted across the country in 2012 and 2014. The activity was part of standard routine monitoring and evaluation activities recommended by GPELF in order to measure impact and success of the National LF Programme over time (WHO, 2011). In total, 40 sites from the original LF surveys were selected based on the geographical distribution of the highest prevalence rates. The first four sentinel sites were surveyed in the Western Province of Zambia in 2012, and the remaining 36 sentinel sites were surveyed in 2014.

At each of the 40 sites between 200 and 300 participants aged $>$ 5 years were recruited and tested for the presence of CFA using the ICT card. For individuals testing ICT positive, a follow-up night blood test was conducted in order to detect the presence of *W. bancrofti* microfilaria (Mf), a marker of current infection, only detectable in the peripheral blood at night. The counting chamber

technique (CCT) was used to detect Mf (McMahon et al., 1979).

2.2. Ethical consideration

All surveys were approved by the University of Zambia Research Ethics Committee, Ministry of Health Zambia and the Liverpool School of Tropical Medicine Research Ethics Committee. Informed consent was obtained from the community leaders and participating individuals. The name, age and sex were recorded of the individuals included in the surveys. Individuals found positive were advised on the preventive measures and referred to the local health clinics.

2.3. ITN coverage patterns 2003 to 2014

To determine the extent of vector control in Zambia from 2003 to 2014, and the potential impact on LF prevalence rates, information on ITNs were obtained from modelled maps of coverage available from the Malaria Atlas Project (MAP) data (http://www.map.ox.ac.uk/). The MAP used spatial statistical methods to produce raster annual coverage maps for the entire African continent. Information on ITN coverage rates across Zambia, and specifically for each of the sentinel sites in each year between 2003 and 2014, were extracted using the mapping software ArcGIS 10 and the zonal statistics tool (ESRI, Redlands, CA). Specifically, buffers with a radius of 1 km, 5 km, 20 km and 50 km were created for each sentinel site using the buffer tool in ArcMap. The average ITN coverage data within these radii for each year between 2003 and 2014 were extracted using the zonal statistics tool. For each LF prevalence measurement at a specific sentinel site in a particular year, the ITN coverage at each radius around that site (1 km, 5 km, 20 km and 50 km respectively) in the year of the LF prevalence measurement and for the four previous years was extracted and tabulated. In addition, the elevation at each sentinel site was extracted from the hydrosheds dataset (http://www.hydrosheds.org/).

2.4. Relationship between LF prevalence and ITN coverage

To better understand whether the observed reduction in prevalence over time was related to ITN coverage over the same period, first a Spearman's rank correlation two-tailed test was performed to measure the direction and association that exist between the LF prevalence and the ITN coverage values. Secondly, two statistical models were developed using LF prevalence and ITN coverage, and elevation data, using linear modelling (LM, function 'lm') within the R statistical environment (R Development Core Team, 2011). Initially, a model (Model 1) that predicted the prevalence at each point in each year using only the 'year' and 'elevation' was created. The parsimony protocol outlined by Crawley as used to produce the Minimum Adequate Model (MAM), i.e. any non-significant values and interaction terms were removed sequentially from the highest order interactions downwards (Crawley, 2007). At each step the significance of deleted items was assessed using analysis of variance using the Chi-squared statistic. As ITN coverage increased over time, it was important to ascertain whether the correlation between ITN use and a decline in LF prevalence could be ascribed only to this covariance. A second model (Model 2) was therefore created that incorporated ITN coverage data. The Chi-squared statistic was used to compare the two models in order to ascertain whether the addition of ITN coverage, added significantly to the model, and therefore whether ITN usage was a significant predictor of LF prevalence.

3. Results

3.1. LF prevalence surveys

The mapping sites and prevalence rates for surveys conducted from 2003 to 2011 are shown in Fig. 1A–B. For the years 2003 and 2005, a total of 3979 individuals (with valid tests) from 42 sites across 14 districts in eight Provinces were examined during the first phase, of which 445 individuals were CFA positive with a 11.5% prevalence rate. Overall Western Province (27.5%) and Lusaka Province (25.1%) had the highest average rates (Table 1), with very high prevalence found at Nalubutu (53.9%), Lwandamo (52.7%) and Kaonga (50.6%) in Kalabo District, Western Province, and at Mphuka Kavalamanja (36.3%) and Mphuka-Janeiro (33.0%) in Luangwa District, and Chanyanya Harbour (30.0%) in Kafue District, Lusaka Province.

For the years 2009 and 2011, a further 5985 individuals (with valid tests) from 66 sites across 58 districts in 9 Provinces were examined, of which 291 individuals were CFA positive with a 4.7% prevalence rate. Overall Northern Province (6.9%) and Southern Province (6.4%) had the highest average rates (Table 1). Very high prevalence was found at Milenge East and Changwe Lungo (20.8%) in Milenge District, Luapula Province, at Mayukwayukwa (14.1%) in Kaoma District, Western Province, and at Chitongo (14.1%) in Namwala District, and Itezhitezhi (14.3%) in Itezhitezhi District, Southern Province. During the two phases of the initial mapping survey, 13 districts from Northern (3), Copperbelt (1), Eastern (4), Luapula (3), Southern (1) and Lusaka (1) were found to be non-endemic with LF prevalence rates $< 1\%$.

The prevalence rates from the sentinel site surveys conducted in 2012 and 2014 are shown in Fig. 1C. A total of 10,995 individuals from the 40 sites across 37 districts in 9 provinces were examined, of which 72 individuals (0.6%) were CFA positive (0.9% of males; 0.5% of females). Overall, Luapula and Central Provinces had the highest average rates at 2.5% and 2.5%, respectively (Table 1). In Luapula Province, the highest prevalence was recorded at Makamba Rural Health Centre (RHC) (5%) in Kawambwa District, and at Kashikishi RHC (4%) in Nchelenge District, while Central Province recorded the highest prevalence rates at Mapepala (9.7%) in Serenje District. The three sites were close to the border of Democratic Republic of Congo (DRC) (Fig. 1B). No individuals tested positive for CFA in Western, Southern and Copperbelt Provinces. Of the 72 CFA positive individuals, 25 (36%) were found to have Mf

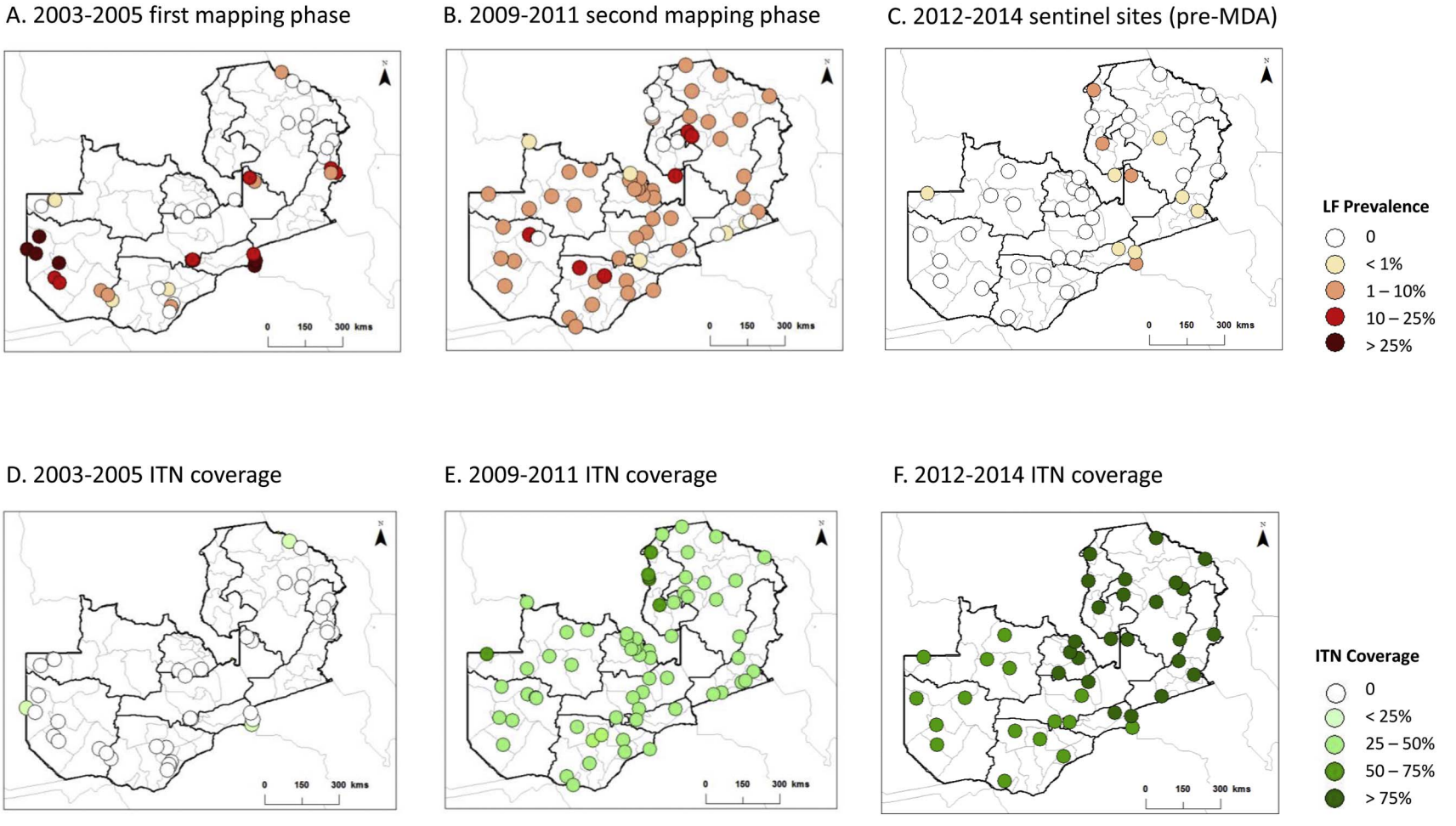

Fig. 1. LF prevalence and ITN coverage rates between 2003 and 2014.

Table 1
LF prevalence and ITN coverage with confidence Intervals by province across three mapping time periods.

Province	LF prevalence (95% CI)			ITN coverage (95% CI)		
	2003–2005	2009–2011	2012–2014	2003–2005	2009–2011	2012–2014
Central	11.9 (0; 38.0)	5.7 (2.3; 9.1)	2.5 (0; 10.1)	0.8 (0; 4.3)	35.1 (28.2; 42.0)	72.4 (53.2; 91.8)
Copperbelt	0 (0; 0)	4.5 (2.2; 6.8)	0 (0; 0)	0 (0; 0)	34.5 (30.9; 38.1)	82.4 (74.8; 89.9)
Eastern	5.6 (0; 12.7)	0.8 (0; 1.6)	0.2 (0; 0.5)	0 (0; 0)	42.0 (40.2; 43.7)	94.1 (88.9; 99.2)
Luapula	–	2.8 (0; 8.0)	2.5 (0; 6.3)	–	53.4 (50.3; 56.4)	95.6 (87.6; 100)
Lusaka	25.1 (14.5; 35.6)	2.0 (0; 26.7)	0.6 (0; 1.7)	0.2 (0; 0.6)	36.1 (3.3; 68.9)	73.2 (59.9; 86.4)
Northern	0.2 (0; 0.7)	6.9 (5.0; 8.8)	0.1 (0; 0.4)	0.5 (0; 0)	39.8 (38.0; 41.7)	81.6 (78.2; 85.0)
North-Western	0.7 (0; 2.6)	3.2 (1.7; 4.7)	0.2 (0; 0.7)	0 (0; 0)	42.2 (34.4; 49.9)	70.5 (63.9; 77.1)
Southern	2.0 (0; 4.9)	6.4 (3.1; 9.7)	0 (0; 0)	0 (0; 0)	27.4 (25.9; 28.8)	53.0 (48.3; 57.7)
Western	27.5 (11.5; 43.6)	6.2 (2.0; 10.4)	0 (0; 0)	0.06 (0; 0.2)	44.0 (40.3; 47.8)	56.3 (51.4; 61.2)
Country	11.5 (6.6; 16.4)	4.7 (3.6; 5.7)	0.6 (0.03; 1.1)	0.2 (0; 0.3)	39.5 (37.4; 41.6)	76.1 (71.4; 80.7)

Note: 2009–2011 prevalence data include 65 sites from 2009 to 2010, and one site from early 2011.

(males 11/38 = 28.9%, females 14/34 = 41.2%). Overall, 80% (n = 20) of the Mf positives came from Luapula, 12% (3) from Northern and 4% (1) each from Lusaka and Eastern Provinces. Notably, all three CFA positive individuals in Mpika District from Northern Province were found to have Mf. When the overall prevalence at each sentinel site in 2003–2005 (11.5%) was compared to 2009–2010 (4.7%) and 2012–2014 (0.6%), a significant reduction (p value = 0.000) was found. The decline was evidence in all areas of the country (Table 1), and the differences are highlighted in Fig. 1 panels A–C.

3.2. ITN coverage rates

The ITN coverage rates for the sites in the two mapping surveys conducted from 2003 to 2011 and the sentinel sites in 2012–2014 are shown in Fig. 1D–F. The overall coverage across all 108 sites was 0.1% in (2003), 0.2% (2004), 0.4% (2005), 17.6% (2006), 25.0% (2007), 35.9.0% (2008), 38.4% (2009), 39.1% (2010), 50.3% (2011), 64.4% (2012), 67.7% (2013), and 73.3% (2014) clearly indicating a staged increase in coverage.

For the sites surveyed for LF in the years 2003–2005, the average ITN coverage in the same year was 0.2% (Table 1). The majority of sites had no ITN coverage above 1% except for Luangwa district, Lusaka Province which had 1.6% coverage. For the sites surveyed in the years 2009–2011, the average ITN coverage was 39.5% with the highest coverage was in Luapula Province (53.4%) and Western Province (44.0%) and the lowest reported in Southern Province (27.4%) (Table 1). The highest ITN coverage was found at Makamba (61.0%) in Kawambwa District and at Lubunda (56.0%) in Mwense District in Luapula Province and Shangombo-Kanja Nangweshi (49.5%) and Itufa-Litambya (49.0%) in Senanga District in Western Province, whilst the lowest was at Chitongo RHC (25.0%) in Namwala district and at Munyumbwe (26.0%) in Gwembe District of Southern Province.

For the sentinel sites conducted in the years 2012–2014, overall the ITN coverage was 76.1% with the highest coverage reported in Luapula Province (95.6%) and Eastern Province (94.1%) and the lowest reported in Southern Province (53.0%) (Table 1). The highest ITN coverage was found at Makamba (97.9%) in Kawambwa District, and Lubunda (99.0%) in Mwense District in Luapula Province, and at Madzimoyo HC (97.3%) in Chipata District and at Mwase-Lunda (95.9%) in Lundazi District of Eastern Province whilst the lowest was reported at Itezhi-tezhi Urban Health Centre (UHC) (51.6%) in Itezhi-tezhi District, and at Makunka RHC (50.7%) in Kazungula District in Southern Province.

3.3. Relationship between LF prevalence and ITN coverage

Spearman's correlation: There was a negative association between LF prevalence and ITN coverage at 5 km radius and at 4 years prior to the LF prevalence value being measured; with a significant spearman's rho correlation of − 0.473 significant at 0.01 level (2-tailed). Similar but less significant correlations were found other radii and for other years. A scatter chart of the data suggested a non-linear relationship; prevalence was transformed using log10(n + 1) to allow for a linear modelling approach.

Linear modelling in R: Using linear modelling in R, a model predicting prevalence from elevation and year was created, which resulted in an R2 value of 0.1772; Year being the most significant factor. The addition of average ITN coverage (specifically in a 5 km

buffer, four years before the prevalence was measured - chosen due to it being the most significant relationship found in the spearman correlation) to the model increased the R2 value to 0.2744; with ITN coverage being the most significant factor. The MAM when including ITN coverage did not also include year, as this variable did not add significantly to the model. The Chi-squared test confirms that this is a significant difference from Model 1, therefore confirming that ITN coverage combined with elevation was found to be a better predictor of LF prevalence than year combined with elevation. The two models are available in the supplementary file.

4. Discussion

This paper highlights the significant decline of LF prevalence across the country between 2003 and 2014. This is of particular importance for the National LF Programme as the very low levels of infection found before the start of mass distribution of albendazole and DEC suggests that other factors contributed to this widespread reduction in prevalence. Evidence elsewhere suggests that the long-running MDA programmes for onchocerciasis using ivermectin may have impacted on LF transmission (Ramaiah and Ottesen, 2014; Koroma et al., 2013). Therefore, an understanding of the extent of all overlapping interventions is important (Kelly-Hope et al., 2011). However, as Zambia is not endemic for onchocerciasis and has never benefitted from an ivermectin MDA programme, it is likely that the significant geographical scale up of ITN coverage for malaria is one factor that has impacted on LF transmission (Kelly-Hope et al., 2013), as evidenced in other LF endemic countries where *Anopheles* are the main vectors (van den Berg et al., 2013).

The observed contrasting LF prevalence and ITN coverage rates suggest that synergies between the LF and malaria control programmes should be further strengthened in Zambia given the potential benefits. The first model showed a decline in prevalence. However, the second model including ITN coverage in a 5 km buffer around each site, and consisting of two elements (variation in ITN coverage over time and variation in ITN coverage geographically), showed a higher R2 value. This suggests that geographical variations in ITN coverage may have influenced the prevalence of LF, as well as the temporal variation that was previously explained using the year variable. Whilst this does suggest a role of ITNs in the control of LF, there may be other confounding factors such as environmental changes, human development and/or indoor residual spraying (IRS) (Kamuliwo et al., 2013) occurring over the same period in a similar geographical pattern that cannot be discounted.

An issue that is not clear from the data or the results is whether there is a causal relationship between ITN coverage and LF prevalence, and in what direction this relationship might be. If the roll-out of ITNs was faster in areas with a higher initial prevalence of LF, this would lead to a correlation between ITN percentage and LF prevalence that was not due to the effect of ITN coverage on prevalence but rather the effect of prevalence on ITN coverage. All that can be said is that the ITN coverage is more closely associated with LF prevalence than year alone. Interestingly the best predictor is not the ITN coverage in the year that prevalence was measured, but rather ITN coverage four years previously. Given the long development period of the disease, this lag does make some intuitive sense and bears further scrutiny. Similarly, the radius around the sentinel sites provided the most significant relationship was 5 km, and may reflect the distance within which people live.

Due to the small number of data points available, especially for later years and the universal dramatic drop in LF prevalence, a spatial model was not attempted for this analysis. However, consideration of spatial factors would be a valuable if more data were available, and may be a consideration for the future surveillance strategies, which could also be integrated with malaria activities. With sound policies attracting partners, and funding for malaria control high, there is mounting evidence of the positive health impacts from malaria control in the country. For example, malaria parasite prevalence in the under-five year old reduced by 50% over a two-year period (21.8% in 2006 to 10.4% in 2008). A further 67% reduction in parasitic prevalence in infants was noted (Chizema-Kawesha et al., 2010) with an incremental overall reduction in infection transmission in those who use a combination of ITNs and IRS (Chanda et al., 2013). This is also reflected in the World Malaria Report of 2013 where malaria hospital admission and death have dramatically fallen between 2001 and 2012.

Given that LF and malaria are transmitted by the same *Anopheles* species, it is likely that the malaria programme's efforts in reducing malaria prevalence over the past decade, have simultaneously impacted on LF transmission, thus reducing the prevalence significantly before the scale up on MDA in 2015 (Kelly-Hope et al., 2013; van den Berg et al., 2013). It is also important to note that Zambia was one of the few countries in sub-Saharan Africa to achieve high coverage of untreated or hand-treated bed nets in the early 2000s, suggesting that the actual net coverage and associated impact could have been higher. Further, one on the main objectives of the National Malaria Control Action Plan in 2010 was to ensure Universal Coverage of Long lasting insecticidal nets (LLINs) through appropriate channels by December to 2011 and maintained through to 2015. As part of the GPELF strategy, the WHO highlights the importance of vector control to enhance the elimination of LF, and emphasises the need for long term relationship between the two programmes (WHO, 2013). Bockarie et al. (2009) also highlighted the potential benefits and the role of vector control in LF programmes, especially where *W. bancrofti* was the main parasite. They indicated that the combination of MDA and ITNs reduced transmission by 90%.

The potential interruption of LF transmission in most regions of Zambia is a positive outcome for the LF programme, despite the slow start of MDA intervention and being behind targets at the GPELF halfway mark in 2010 (WHO, 2010). This observation suggests that the WHO recommended 5–6 rounds of MDA required to interrupt transmission, may potentially be reduced to fewer rounds of MDA with the consultation and agreement of the AFRO Regional Programme Review Group (RPRG). This will enable the LF programme to potentially finish MDA in 2018, start surveillance activities, focus on any persistent areas with targeted interventions. This will help the programme to meet the GPELF elimination goals by shrinking the map by some 11 million people. Specific follow-up assessments will need to be prioritized to areas still showing evidence of ongoing transmission, especially those bordering the DRC, which may be attributed to cross border migration. However, a similar situation in this area is evident with malaria transmission that

is persisting despite the extensive distribution of ITNs interventions, which suggest that the problem could also be related to other factors such as mosquitoes being resistant to the insecticides used for ITNs (Chanda et al., 2011; Wiebe et al., 2017).

Moving forward, the LF programmes will need to concentrate on the "endgame surveillance" strategies that will be most effective. LF should aim to integrate key monitoring activities with the malaria control programme to optimise human, technical and financial resources in the long-term, this may include xeno-monitoring of infection in the mosquitoes by both parasites, and will be cardinal even when Mf infection declines in humans, to confirm similar decline of Mf infection in the mosquitoes and monitor any possibility of recrudescence (Bockarie et al., 2009). Identification of areas with persistent LF or where mosquitoes are resistant to the insecticides used with ITNs and IRS, will help to focus interventions (Coleman et al., 2017). The districts bordering DRC where there was evidence of ongoing transmission should be investigated further and surveillance strengthened. It may be that the triple drug treatment using DEC, albendazole and ivermectin (Thomsen et al., 2016; Irvine et al., 2016) could be used in any remaining hotspots to accelerate progress to meet the national and global targets of LF elimination by 2020. Such multipronged approaches will maximise the use of interventions and resources, and build synergies between the programmes, which will help to strengthen health systems at all levels.

Author contributions

Mutale Nsakashalo-Senkwe: field work, data collation, preliminary analysis, first draft of paper.
Enala Mwase, Elizabeth Chizema, Victor Mukonka, Peter Songolo, Freddie Masaninga: in-country field and data support.
Brent Thomas: field work, data collection and collation.
Maria Rebollo, Moses Bockarie: fieldwork work in Western Province.
Russ Stothard: data analysis and draft of paper.
Hannah Betts: statistics and model development.
Louise Kelly-Hope: field work, concept of paper, analysis, maps, first draft of paper.
All authors contributed to the manuscript.

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Competing interest

The authors declared they have no competing interest.

Appendix A. Supplementary data

Supplementary data to this article can be found online at http://dx.doi.org/10.1016/j.parepi.2017.08.001.

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