# SOCIAL AND MOLECULAR EPIDEMIOLOGY OF HIV AMONG KEY POPULATIONS IN NIGERIA: LINKING TRANSMISSION INSIGHTS TO TARGETED PREVENTION

by

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## Abstract

Nigeria has a mixed HIV epidemic in which key populations – female sex workers (FSW), men who have sex with men (MSM), people who inject drugs (PWID), and transgender people – bear a disproportionate burden of HIV, yet molecular evidence characterizing this remains scarce. This thesis, guided by a programme science approach, combined a narrative review and molecular epidemiological analyses to characterize HIV transmission among four Nigerian key populations and inform more effective programming. Objective 1 used the modified social ecological model to organize a narrative review of 36 studies conducted among Nigerian key populations, identifying determinants of HIV prevention, testing, and treatment outcomes across individual, network, community, and policy levels. Criminalization, stigma, and programme delivery emerged as recurring structural barriers operating across several ecological levels. Objective 2 applied phylogenetic clustering and Bayesian phylodynamic modelling to the 2020 Nigerian Integrated Biological and Behavioural Surveillance Survey (IBBSS) and evaluated associations using multivariable Poisson regression. HIV protease sequences derived from 547 IBBSS participants (n=185 FSW, n=176 MSM, n=51 PWID, and n=135 transgender people) formed 47 phylogenetic clusters. After adjustment, transgender people had 5.52 times [95% CI: 2.96-10.28, $p < 0.001$] and MSM had 5.38 times [95% CI: 2.87-10.07, $p < 0.001$] higher prevalence in phylogenetic clusters relative to FSW, and geopolitical zone remained a significant predictor. Growth phases in median number of effective infections for HIV subtypes CRF02_AG (n=364) and G (n=139) between 2000–2020 aligned with rises in national HIV case counts and persisted during early-stage treatment scale-up, consistent with interventions still building toward the intensity needed to reduce transmission among key populations. Structured coalescent models identified conserved ancestral migration events between MSM and transgender people

for both subtypes, while ancestral migration events between northern and southern geopolitical zones differed in direction and magnitude across subtypes. Framing molecular findings with individual-, network-, community-, and policy-level contexts strengthened this study's relevance to programme planning and the needs of IBBSS partners, while providing molecular evidence that HIV transmission is not siloed, but cuts across both key population groups and geopolitical zones and highlights a need for sustained, integrated programming in Nigeria.

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## List of Abbreviations

| | |
|---|---|
| AIDS | Acquired Immunodeficiency Syndrome |
| aPR | Adjusted Prevalence Ratio |
| ART | Antiretroviral Therapy |
| BEAST | Bayesian Evolutionary Analysis by Sampling Trees |
| CI | Confidence Interval |
| FSW | Female Sex Workers |
| GTR | General Time Reversible |
| HIV | Human Immunodeficiency Virus |
| HPD | Highest Posterior Density |
| HREB | Health Research Ethics Board |
| IGPH | Institute for Global Public Health |
| KPSE | Key Population Size Estimate |
| MCMC | Markov Chain Monte Carlo |
| MPPI | Minimum Prevention Package Intervention |
| MSM | Men who have Sex with Men |
| NACA | National Agency for the Control of Aids |
| $N_e$ | Effective population size |
| PR | Prevalence Ratio |
| PrEP | Pre-Exposure Prophylaxis |
| PWID | People Who Inject Drugs |
| SH-aLRT | Shimodaira-Hasegawa-like approximate Likelihood Ratio Test |

| | |
|---|---|
| STBBI | Sexually Transmitted and Bloodborne Infection |
| TasP | Treatment as Prevention |
| WACPHD | West African Centre for Public Health Development |
| WHO | World Health Organization |
| UFBoot | Ultra-fast bootstrap |

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# CHAPTER 1 INTRODUCTION AND STUDY OBJECTIVES

## 1.1. Introduction

Human Immunodeficiency Virus (HIV) remains a significant public health challenge in Nigeria.[1, 2] Nigeria has a mixed HIV epidemic, with high prevalence in the broader adult population and a disproportionately high prevalence among key populations – female sex workers (FSW), men who have sex with men (MSM), people who inject drugs (PWID), and transgender people.[3] The marginalized status of key populations is fueled by stigma, discrimination, and their criminalized status.[4] While HIV incidence has decreased among the Nigerian general population, attributed to effective intervention and treatment, incidence has increased in key populations, highlighting the need to prioritize resources among the most vulnerable to progress towards epidemic control.[4, 5]

The implementation of the first national Integrated Biological and Behavioural Surveillance Survey (IBBSS) in 2007,[6] and subsequent rounds in 2010,[7] 2014,[8] and 2020,[9] represents a novel effort in Nigeria to systematically capture population-based biological and behavioural data from key populations related to HIV. The most recent IBBSS was conducted across 12 states, encompassing all six of the country's geopolitical zones, with a low- and high-prevalence state selected from each zone.[9] These surveys have provided invaluable insights into HIV prevalence, sexual and injecting behaviours, and engagement with prevention and treatment services, helping to evaluate the epidemic response and inform public health policy and programming.[6-9] Additionally, the IBBSS have underscored the importance of prioritizing key population groups in HIV resource allocation and programming to improve health outcomes. However, despite four rounds of cross-sectional IBBSS and the introduction of programmes

tailored specifically for key populations,[10-15] recent estimates suggest that HIV prevalence continues to increase among most key populations.[16, 17]

Recent policy changes and funding cuts to U.S. development assistance for health, announced in January 2025, pose a substantial threat to sustaining the country's momentum in epidemic control. Before 2025, contributions from the U.S. President's Emergency Plan for AIDS Relief (PEPFAR) comprised 90% of the country's HIV treatment budget, including the support of antiretroviral therapy (ART) procurement, clinical services, and community-based outreach.[18] Given that large-scale, cost- and time-intensive surveys such as IBBSS may no longer be feasible under reduced funding, leveraging data from the most recent IBBSS is both timely and necessary.

Advances in genetic sequencing over the last decade have allowed HIV to be studied not just as a clinical condition, but as an evolving epidemic. These methods are known as molecular phylogenetics.[19] Viral sequences with high genetic similarity form linkages on phylogenetic trees, constituting what is defined as a phylogenetic cluster. These clusters can be used to infer recent transmission chains and identify priority populations experiencing high rates of transmission events for improved outreach and care.[20] Viral diversity can also be modelled using phylodynamics, which is useful in low-sampling-density settings to estimate the growth of epidemics and inform prevention programmes.[21]

Although noted as an insightful technology,[19, 22] there is little molecular evidence offering novel insights into the HIV epidemic in Nigeria,[21, 23-26] and such evidence is seldom combined with other indicators, such as utilization of prevention or treatment services.[21, 25] Given Nigeria's mixed HIV epidemic, which necessitates interventions among several populations, examining how phylogenetic clusters connect key populations and how epidemic trajectories vary by

population and geopolitical zones provides valuable insights for evaluating the epidemic response and refining targeted interventions. The current study presents secondary analyses of data collected during the 2020 Nigerian IBBSS among four key populations–FSW, MSM, PWID, and transgender people–and harnesses HIV molecular epidemiological methods to generate evidence-based insights that have the potential to inform targeted prevention strategies for key populations living with HIV in Nigeria.

### 1.2. Purpose

The purpose of this study was to harness HIV molecular epidemiological methods to generate evidence-based insights that can inform targeted prevention strategies among key populations in Nigeria. Rather than attributing HIV prevalence and transmission insights to intrinsic, individual-level behavioural characteristics, the current study was guided by a programme science approach[27, 28] and informed by a modified social ecological model.[29] By synthesizing diverse data types under this framework and approach, guided by international partnership, this study aimed to provide a more comprehensive understanding of the multi-level (individual, network, community, and policy) determinants shaping HIV transmission dynamics among four key populations in Nigeria. This enabled increased granularity in epidemic understanding to ultimately inform more effective, tailored programmes.

### 1.3. Research Objectives

#### 1.3.1. Objective 1 and associated research questions

Through a narrative review, Objective 1 of this study was to develop an understanding of the social determinants of both HIV acquisition and programme service utilization among key populations in Nigeria. This step was necessary to provide comprehensive knowledge and

understanding of the social and structural conditions sustaining the HIV epidemic and to identify how these determinants influence programme engagement. Specifically, it explored:

1. How have Nigeria's social and structural contexts affected:
    a. HIV acquisition and transmission risk; and
    b. HIV prevention and treatment service engagement among key populations?

To answer this, the modified social ecological model served as an organizing framework to classify determinants identified in the literature across individual, network, community, and policy levels, as well as by epidemic phase. This approach enabled a comprehensive analysis of how different dimensions of Nigeria's context contribute to both growth and mitigation of the HIV epidemic. No hypotheses were tested for Objective 1 due to its exploratory nature.

#### 1.3.2. Objective 2 and associated research questions

Objective 2 of this study aimed to combine HIV molecular methods, specifically phylogenetic cluster and phylodynamic modelling, with behavioural data to provide a more comprehensive understanding of Nigeria's epidemic among key populations. This objective linked patterns of transmission, epidemic trajectories and key behavioural data to programmatic contexts, with the goal of strengthening intervention design and delivery. Specifically, it explored:

1. What do recent HIV transmission chains inferred from phylogenetic clusters reveal about the connectivity and interaction between key populations and geopolitical zones in Nigeria, and how might these insights inform targeted prevention strategies?

To answer this, maximum-likelihood phylogenetic trees were generated with IBBSS participant and publicly available Nigerian HIV protease sequences, where phylogenetic clusters were determined using a pre-defined distance threshold and utilized to infer recent transmission

chains.[20] Descriptive statistics and regression modelling were used to assess sociodemographic, behavioural, and programme engagement characteristics associated with membership in phylogenetic clusters. It was hypothesized that individuals of the same key population would demonstrate similar behaviours and population-joining linkages would be formed mainly by MSM, reflecting overlap in underlying social networks, whether sexual or injecting, across multiple populations. Due to the tendency of phylogenetic inference to detect recent transmission events, it was hypothesized that those present in clusters would be of younger age and report low prior awareness, contact, and utilization of HIV testing services.

2. How do HIV epidemic trajectories and viral ancestral migration events differ across key populations and geopolitical zones, and what implications do these patterns have for intervention programmes within the Nigerian context?

To answer this portion of Objective 2, phylodynamic modelling in BEAST2 was conducted using skyline plots to reconstruct epidemic size changes over time and migration models to estimate the timing and magnitude of viral connectivity between geopolitical zones and key populations.[30, 31] It was hypothesized that HIV epidemic trajectories would differ substantially across key populations. Specifically, MSM and transgender people would exhibit higher effective population sizes indicative of recent growth phases, given the increased HIV prevalence among these populations in recent IBBSS rounds that has yet to plateau.[9] By geopolitical zone, a higher number of ancestral migration events and earlier introductions were hypothesized in southern zones compared to northern zones, reflecting differences in mobility, stigma, and healthcare access.[32-35] Overall, zones and key populations with larger epidemic expansion/migration events would correspond to areas where HIV programmes face gaps in coverage, highlighting a need for improved awareness, outreach, and utilization.

## 1.4. Ethical Considerations

As Objective 1 of this study was a narrative review of publicly available peer-reviewed literature and gray literature sources, no ethical approval was sought. Objective 2 was completed as a secondary analysis of existing data gathered from the 2020 Nigerian IBBSS.

### 1.4.1. Ethical approval

Ethical approval for Objective 2 was obtained from the University of Manitoba's Health Research Ethics Board (HREB). The letter of final approval [Harmony ID 4429: 03/03/2026-03/03/2027] is included in Appendix A. Ethical approvals for the 2020 Nigerian IBBSS were obtained from the HREB [HS23933-H2020:231] and the National Health Research Ethics Committee, Nigeria, [NHREC/01/01/2007-25/08/2020], with the primary HREB certificate included in Appendix B. Primary study ethical approvals are overseen by Nigeria's National Agency for the Control of AIDS (NACA).

### 1.4.2. Risks and benefits

Both objectives of this study focused on key populations in Nigeria who are highly marginalized, stigmatized, and criminalized. For Objective 1, if determinants were not contextualized carefully, the review risked reinforcing stereotypes and stigma experienced by key populations. Moreover, an overemphasis on published literature could exclude underrepresented voices whose experiences are less likely to be recognized. Objective 2 was also accompanied by several potential risks. Primarily, this includes breaches of confidentiality, stigma, and legal consequences due to the criminalization of certain key population-defining behaviours.

The primary benefit of this study was its potential to improve understanding of the multi-level factors influencing HIV epidemics across Nigerian key populations, and to produce insights that could be fed back into programmes to improve outreach and care for these populations. The

proposed analyses were supervised by the primary advisor, with all findings and interpretation guided by the goals and perspectives of the government- and community-facing organizations on the IBBSS team that requested these analyses.

#### 1.4.3. Informed consent

No informed consent was required for the narrative review, as data collection involves publicly available and peer-reviewed literature sources. For Objective 2, verbal informed consent was obtained for both biological and questionnaire components of the IBBSS (and its downstream projects) during primary data collection rather than written consent.

#### 1.4.4. Privacy and confidentiality

No personally identifiable information was provided during the survey, and both questionnaires and specimens were linked to non-identifiable study codes. Since this was a secondary analysis, no new recruitment or direct contact with individuals was required. All data generated were stored via OneDrive to meet data security requirements. In the event of publication of this material, reasonable requests to access the data will be considered and indicated within a data availability statement.

# CHAPTER 2 LITERATURE REVIEW

## 2.1. HIV epidemic in Nigeria

HIV was first reported in Nigeria in 1985, a few years after the first case on the African continent was reported in Uganda in 1982.[36] The country's first two cases of HIV were reported among a 13-year-old girl and a female sex worker from a neighbouring West African country in the Southern cities of Lagos and Enugu, respectively.[1, 37] Early public perception in the 1980s and 1990s was challenged by limited access to information about HIV/AIDS, contributing to misinformation, widespread fear, discrimination, and shame, which created significant physical and psychological burdens on people living with HIV at the time.[37-39] The steady rise in cases during the 1990s underscored the need for a coordinated, multisectoral approach to HIV prevention that addressed social and developmental dimensions of health, which was formally adopted in 1999 with the establishment of the National Action Committee on AIDS, which has since been renamed to the National Agency for the Control of AIDS (NACA).[38]

Nigeria's national ART treatment programme was announced in 2001, marking the first of its kind in Africa.[38] Despite these efforts, the estimated 5% HIV prevalence in 2004 indicated that HIV remained a major public health crisis.[38] Spurred by national and international activism, HIV user fees for health care facilities were removed in 2005, and treatment delivery was decentralized from federal medical centres to state hospitals.[38] From 2005 to 2014, a significant expansion in HIV prevention, testing, and treatment programmes occurred, supported by a large influx of external donor funding and high-level political commitment.[38] Advances in rights-based movements also occurred, such as the HIV and AIDS (Anti-Discrimination) Bill in 2014.[38] However, the enactment of the Same-Sex Marriage (Prohibition) Act in the same year, which

remains in effect, reflected continuing legal and social barriers for sexual minorities and people living with HIV.[38, 40]

Today, Nigeria is the most populous African country and has the world's second-largest number of people living with HIV.[9] In 2019, an estimated 1.9 million Nigerian adults aged 15-49 years were living with HIV, with an incidence of 8.0 per 10,000 persons across both genders and age groups.[41] Despite representing only 3.4% of the Nigerian adult population, FSW, MSM, and PWID, along with their sexual partners, accounted for 32% of new HIV infections in 2017.[42] In 2021, HIV prevalence in Nigeria was reported to be highest among transgender people (28.8%), followed by MSM (25.0%), FSW (15.5%), and PWID (10.9%).[16] However, significant regional heterogeneity in prevalence was observed across the country's geopolitical zones during the 2020 IBBSS among transgender people (7-47%), MSM (7-37%), FSW (6-27%), and PWID (1-23%).[16] The marginalized status of FSW, MSM, PWID, and transgender people exacerbates the burden of HIV and is driven by sociocultural factors such as stigma and discrimination – including societal and religious disapproval – poverty, gender inequality, and sexual- and gender-based violence.[43-47] Enacted or perceived stigma has been found to impede individuals who belong to key populations from seeking HIV testing, receiving care, and remaining adherent to treatment.[4, 48-53]

Nigerian literature has recognized HIV transmission among FSW to be fueled by the criminalization of sex work, police harassment, and societal stigma, which have been linked to poverty and injection drug use.[4, 42, 54, 55] Similarly, previous studies identify Nigerian MSM to experience heightened HIV risk through the criminalization of same-sex marriage and practices (i.e., public relationships).[40] This policy has been associated with an overall avoidance of healthcare by MSM, including HIV testing,[4, 56] and may impact transgender people as well.[57, 58]

Additionally, social oppression experienced by Nigerian MSM has been found to negatively affect psychological health and heighten vulnerabilities such as substance use.[59-61] Reported rates of homelessness are increased among PWID in Nigeria and have been associated with an increased likelihood of sharing needles or syringes and experiencing stigma, police harassment, and drug-related violence.[62, 63] This is exacerbated by geographic gaps in harm reduction service coverage and the limited range of services offered,[64] which may impede HIV prevention efforts.

Within these complex and dynamic network, community, structural, and legislative contexts, individuals congregate and socialize in ways that actualize and perpetuate HIV risk.[65] More specifically, the locations where people gather are socially constructed, temporarily stabilized by shared norms and rules, and have the power to enable or constrain different behaviours.[66] For instance, transmission of HIV is heavily influenced by complex interactions within social networks, such as sexual or injecting networks, where the most prevalent behaviours, like needle-sharing or condomless sex, can become normalized.[67, 68] Given the scale and complexities of Nigeria's HIV epidemic, worsened by funding cessation, there is a pressing need for precise, targeted prevention and treatment interventions that are contextually informed at the individual-, network-, community-, policy-, and epidemic stage levels, including inter- and intra-transmission dynamics among key population groups.

### 2.2. Programme science as an approach to HIV reduction

Interventions at the individual, group, and structural levels have been critiqued for being inadequate for slowing HIV and other sexually transmitted and bloodborne infection (STBBI) epidemics, largely due to insufficient use of scientific evidence to inform programmatic decisions and a disconnect between identified priorities among researchers and programme implementers.[27] Programme Science has the potential to enable meaningful collaboration

between programmes and science, jointly engaging scientists and programme planners in the development and refinement of intervention strategies to resolve programme issues. This approach emphasizes the ongoing generation of scientific evidence that informs decision-making for prioritizing populations and geographies that will benefit most from programmeservices.[65] To this end, programme science aims to generate knowledge derived from programmatic questions to guide further scientific inquiry and produce additional evidence that can be incorporated back into the programme to optimize services, with the goal of achieving population-level impact.[69]

Within a programme science approach, insights into epidemiology and transmission dynamics can guide strategic planning by defining prevention objectives, identifying priority populations and geographies, and aligning interventions with the current epidemic phase.[27] Targeting interventions to those most at risk of acquisition, as well as those who are most likely to transmit the infection to others, is critical.[70] Beyond this, due to the possibility of several localized, contained HIV epidemics and significant heterogeneity in prevalence, incidence, and risk across subpopulations and places, geography becomes a vital consideration in the placement of interventions.[28] The timing of interventions can also be important if diagnoses and/or treatment are delayed, particularly while a person living with HIV continues to engage in sexual relationships or shared injection practices during periods of high infectiousness, such as in early infection.[70] In sum, identifying localized clustering of new infections, in terms of both population group and geographical location, can prove informative for both implementing new prevention programmes and improving coverage and scale-up of existing programmes designed for key populations.[70]

Another key element of programme science is the development of long-term, sustainable partnerships between programmes, organizations, institutions, and stakeholders, which ensures

that the research is equity-focused and closely tied to the priorities of the community.[65] These priorities should be regularly and iteratively identified through ongoing consultation with partners throughout all phases of research, from design to interpretation. This collaborative approach also emphasizes the importance of identifying and addressing the larger socio-structural factors leading to inequities in health service coverage among marginalized groups, rather than narrowly focusing on the negative impact of these inequities on individual group members.[65] Ecologic, or place-based approaches, shift attention away from individualistic models of risk and behaviour in favour of social and environmental change.[71] In other words, instead of looking solely at "high-risk" behaviours that individuals, or their social networks, engage in, the exposure to structures and environments is what creates the risk of HIV and other STBBI.[65]

### 2.3. Modified social ecological model for HIV risk

Baral's *Modified Social Ecological Model* takes this a step further.[29] The model postulates that while individual-level risk (e.g., needle sharing and condomless sex) is necessary for HIV acquisition and transmission, higher-order socio-structural factors beyond individual control enable or constrain HIV transmission at the population level.[29] The modified social ecological model expands existing social ecological frameworks by situating individual-level HIV risk within broader network, community, and policy environments, while also accounting for the stage of the epidemic.

Based on the modified social ecological model, HIV and STBBI risk reduction at the individual level does not occur in isolation, but is shaped by power imbalances in risk negotiation,[71] which may be influenced by gender, age, socioeconomic status, education, ethnicity, or the criminalization of certain behaviours, and limits the extent to which individuals

can control their risk. Despite this, policymakers often narrowly target interventions towards individual-level behaviours.[29] To this end, effective HIV programmes must not only account for heterogeneity in risk across populations and geographies and the structural contexts in which risk is produced, but also for the epidemic phase that creates tangible risk. Therefore, reducing HIV risk at the population level must involve coordinated action across individual, community, policy levels,[71] and be informed by where the epidemic currently stands.[29]

## 2.4. Applications of HIV molecular epidemiology

Given the emphasis of programme science to use the best available evidence to optimize interventions, molecular epidemiology offers a new evidence base at the forefront of genetic research that can complement traditional epidemiological data.

### 2.4.1. Phylogenetic cluster inference

Characterizing the factors contributing to the formation of transmission clusters among each key population is crucial to target HIV control strategies towards the most concentrated local epidemics.[25] Understanding transmission dynamics within and between key populations can be challenging when relying on surveys alone, however, insights can be gained through molecular phylogenetics. Phylogenetics is a method used to generate hypotheses about the relationship between ancestor and descendant genetic sequences, as the genetic distances, or branch lengths, on a phylogenetic tree reflect how closely related sequences are.[72] In the case of HIV, phylogenies can be constructed from viral sequences obtained from specimens collected from people living with HIV, such as plasma or dried blood spots (DBS), and recent transmission chains can be inferred from highly similar viral sequences, which cluster together within the tree.[19, 73, 74] The HIV *pol* gene is often used in molecular phylogenetics because of its regular sequencing for drug resistance genotyping, paired with its sufficient genetic information, or

phylogenetic signal. Although there is no universally accepted definition for a transmission cluster inferred from a phylogenetic cluster, a distance threshold of <0.02 (i.e., 2%) substitutions per site has been shown to be a natural breakpoint observed between intra- and inter-patient HIV diversity and correlate well with genuine transmission events.[20]

When combined with geographical, demographic, and behavioural data, phylogenetic clustering studies have been shown to improve targeted intervention efforts and enhance epidemic response.[20, 74] Canada was one of the first countries to incorporate molecular epidemiology, specifically phylogenetic cluster detection, into its routine surveillance efforts.[20] Through the use of HIV genomic data, Poon et al. (2016) were able to identify a growing cluster of viruses and implement a timely public health response that heightened contact tracing, enhanced linkage to care and early treatment initiation, ultimately resulting in reduced community transmission.[20]

Despite Nigeria's large, mixed epidemic, molecular epidemiological insights remain limited. Few phylogenetic studies have been conducted in the country,[23-25] with only a single study focusing on a key population,[25] leaving major gaps in understanding transmission dynamics. Li et al. (2020) constructed phylogenetic trees among Nigerian MSM living with HIV and identified relatively large clusters of up to 15 individuals containing both MSM (MSM-only) and bisexual MSM.[25] They observed frequent clustering among MSM who were treatment-naïve, engaged in same-sex sexual practices, did not consistently use condoms, or had an active bacterial sexually transmitted infection.[25]

Several studies from other sub-Saharan African countries have illustrated the applications of phylogenetic cluster analysis to characterize recent transmission chains among key populations.[75-80] In Kenya, a study by Cholette et al. (2024) observed that phylogenetic clustering

frequently occurred among MSM who sought sexual partners online and tested for HIV infrequently, emphasizing the unmet needs of this population and the importance of tailored programmes across the different venues (both physical and virtual) used by Kenyan MSM to find sexual partners.[75] Another Kenyan study by Nduva et al. (2020) reported phylogenetic clustering within key populations, such as MSM-exclusive and PWID-exclusive clusters, in addition to mixed phylogenetic clustering between these populations,[76] which has also been observed in Senegal and Togo.[77, 78] In coastal Uganda, Bbosa et al. (2020) found that FSW tended to form phylogenetic clusters among other FSW, with limited linkages between FSW and male clients indicative of heterosexual sex work.[79] While this could be driven by true linkages between FSW (i.e., injecting networks), they also may be linked indirectly through male clients, but there is a lack of evidence for such an interaction, as clients are rarely sampled. There is an overall scarcity of phylogenetic studies conducted among transgender people in sub-Saharan Africa, with studies including too few of these participants or reporting low sampling density, resulting in inadequate results to assess HIV transmission dynamics among this population.[25, 80]

While phylogenetic clustering studies are useful for inferring epidemiological relationships, these methods have been shown to be confounded by variables associated with recent infection, and chronic, established infections are less likely to form clusters.[81] Therefore, although valuable for investigating a particular phase of transmission (e.g., early, acute stage infection), model-based phylodynamic approaches have the potential to expand these insights to explore transmission dynamics and migration of lineages over extended periods of time.[21]

#### 2.4.2. Phylodynamic modelling

Phylodynamic models focus on estimating population dynamic parameters, which can be accomplished using a Bayesian statistical framework.[82] Phylodynamics operates on the principle

that since population dynamics will influence the shape of trees, a given tree topology can be used to infer information about population dynamics. In such models, estimates of the posterior distributions for model parameters are based on interactions between the prior (informed by literature) and likelihood (derived from the sequence data) functions using a Markov Chain Monte Carlo (MCMC) process (e.g., chain length and parameter mixing). This is achieved by constructing time-stamped phylogenetic trees through the incorporation of statistical models, such as nucleotide substitution and molecular clock models.[72] These statistical models also include a tree prior, which defines the expected distribution of phylogenetic tree shapes and branching times. For instance, a coalescent tree prior is grounded in the principle of working backwards in time to trace when viral lineages in a phylodynamic tree last shared a common ancestor, or the point at which they "coalesce".[30]

A useful epidemiological estimate obtained from coalescent phylodynamic models include the effective population size (or $N_e$), which reflects the relative size of the transmitting population based on viral diversity and allows changes in transmission intensity to be detected over time.[30] Transmission intensity may reflect a combination of factors, including earlier introduction and expansion of the virus into the population, or the effect of programming, ART access, behavioural or network changes, or gaps in services. For example, broad phases of epidemic exponential growth might suggest a population has delayed or lower effective ART coverage, a plateau suggests transmission has slowed to a steady state, while success in treatment-as-prevention (TasP) should eventually result in a declining $N_e$. However, it should be emphasized that this statistic is a relative genetic signal, not a direct case count, and is highly influenced by who was sampled and when.

Another useful estimate is the median number of ancestral migration events, which is the movement of a viral lineage from one subpopulation/geography into another.[83] This is produced using a structured coalescent approach, which extends coalescent approaches by incorporating geography and allowing for a population to be divided into meaningful groups (subpopulations) rather than a single, well-mixed population. This enables pathogen migration patterns to be inferred and the directionality and magnitude of transmission events to be estimated between smaller population groups and geographic regions. This estimate provides evidence of viral lineage connectivity between sampled population groups and should be interpreted as such, as opposed to providing direct transmission direction between individuals or assigning source status to a population group. A median ancestral migration events value > 1.0 suggests that the model inferred multiple historical movements of viral lineages between the groups or regions being compared, indicating ongoing epidemiologic connectivity.

Phylodynamic methods have been previously applied to evaluate and improve programmatic interventions.[84-86] For instance, Vasylyeva et al. (2020) utilized city-level phylodynamic models to evaluate the impact of an HIV intervention in Odesa, Ukraine by comparing inferred population dynamic parameters, before and after the intervention, to the same measures in Kyiv.[85] In South Africa, Wilkinson et al. (2019) modelled changes in reproductive number and effective population size following the expansion of antiretroviral therapy and public health campaigns for medical male circumcision, though only at a national level.[84] Similarly, Cholette et al. (2020) applied structured phylodynamic models to examine the role of migration among PWID in Pakistan in driving HIV expansion, identifying regional hubs where injecting networks concentrated and disseminated outward, informing targeted public health policies.[86]

Numerous phylodynamic studies have been conducted in Nigeria[21, 24] and elsewhere in sub-Saharan Africa.[21, 76, 84, 87-97] Most emphasize generalized epidemics at national scales, seeking to characterize the origin and spread of HIV epidemics in each country. Further, only a fraction of these studies have focused on key populations, and when they do, the emphasis is typically on MSM,[21, 95, 96] with FSW, PWID, and/or transgender groups rarely included.[76, 97] For instance, Nduva et al. (2022) analyzed HIV migration across Kenyan key populations and reported higher rates of transmission within risk groups compared to between risk groups, challenging the assumption that key populations disproportionately transmit HIV to the broader, heterosexual population.[97] They also observed a dominance of west-to-east dissemination of HIV from regions of high-to-low prevalence,[97] whereas Grabowski et al. (2020) found the opposite pattern in Uganda, reporting viral flow from low-to-high prevalence populations.[98] In Nigeria, Volz et al. (2017) used extended phylodynamic modelling to explore the impact of meeting the 90-90-90 targets among Nigerian MSM by 2021, providing valuable national-level cost-saving estimates but limited sub-national insights.[21] While these studies demonstrate the value of phylodynamics and an ability to produce sub-nationally relevant data, their practical translation can be constrained if data limitations prevent the level of granularity needed to inform specific programme refinements.

### 2.5. Limitations of review

This literature review aims to provide a critical review of the HIV epidemic in Nigeria, a brief introduction to Programme Science, a framework for understanding HIV risk, and how molecular epidemiology can be applied to generate epidemic and programmatic insights. After identifying the multi-level factors contributing to the social context in which Nigerian key populations are marginalized and experience disproportionate risk of HIV, the applications and

contributions of molecular epidemiological tools to prevention programme initiatives will be discussed.

While the brief review within this proposal cannot fully capture the nuanced political, social, and economic factors that have influenced Nigeria's HIV progression and response, these factors remain critical to understanding the epidemic's broader context.

# CHAPTER 3 METHODOLOGY

## 3.1. Theoretical framework

This study utilized Baral's *Modified Social Ecological Model* (Figure 1),[29] in addition to being guided by a programme science approach.[27, 69] Within the modified social ecological model, individual risk is the innermost level and includes biological or behavioural factors associated with HIV acquisition or transmission. Social and sexual network-level risks eclipse individual risk. The network level is groups of people who are predisposed to HIV risk based on their interpersonal affiliations and includes behavioral factors that potentiate HIV transmission among individual members of a network. It also encompasses familial/social support that may promote or discourage protective behaviours. It is within these networks that social interactions occur and behaviours become normalized. Beyond this is community-level risk, which determines access to services and can serve to promote health or reinforce stigma/discrimination. This level is typically where stigma manifests and can limit the provision and/or uptake of HIV prevention, treatment, and care services. Communities can be defined by cultural, economic, religious, political, or geographic characteristics. Policy-level risk includes the implementation of policies that influence the ability to decrease HIV risk, such as the criminalization of key population-defining behaviours and perceived lifestyles and occupations imposed on key population members.

Finally, beyond each social ecological level is the epidemic stage. Regardless of risk at any other sub-level, it is the epidemic stage at a network, community, and/or national level that increases or decreases the probability of HIV acquisition and transmission. For instance, condomless anal intercourse can only be described as carrying a high risk of HIV if it occurs within a network that faces a large burden of HIV prevalence and unsuppressed viral load.[29] The

modified social ecological model was used as an organizing framework for the narrative review to classify determinants at individual, network, community, and structural levels, in addition to the HIV epidemic phase, to ensure a comprehensive discussion of factors shaping both HIV acquisition and programme utilization.

Programme science as an approach for public health planning is useful for linking scientific evidence across the programme cycle (i.e., programme planning, implementation, evaluation) and has been shown to inform and improve HIV/STBBI programmes.[69] Moreover, this approach recognizes the complexity of evolving epidemics while underscoring the need for responses that can be adapted continuously and systematically.[99] For the current study, local epidemiological insights obtained from both objectives were assessed through the lens of strategic planning, programme implementation and evaluation, with emphasis on producing evidence that could be incorporated back into programme design.

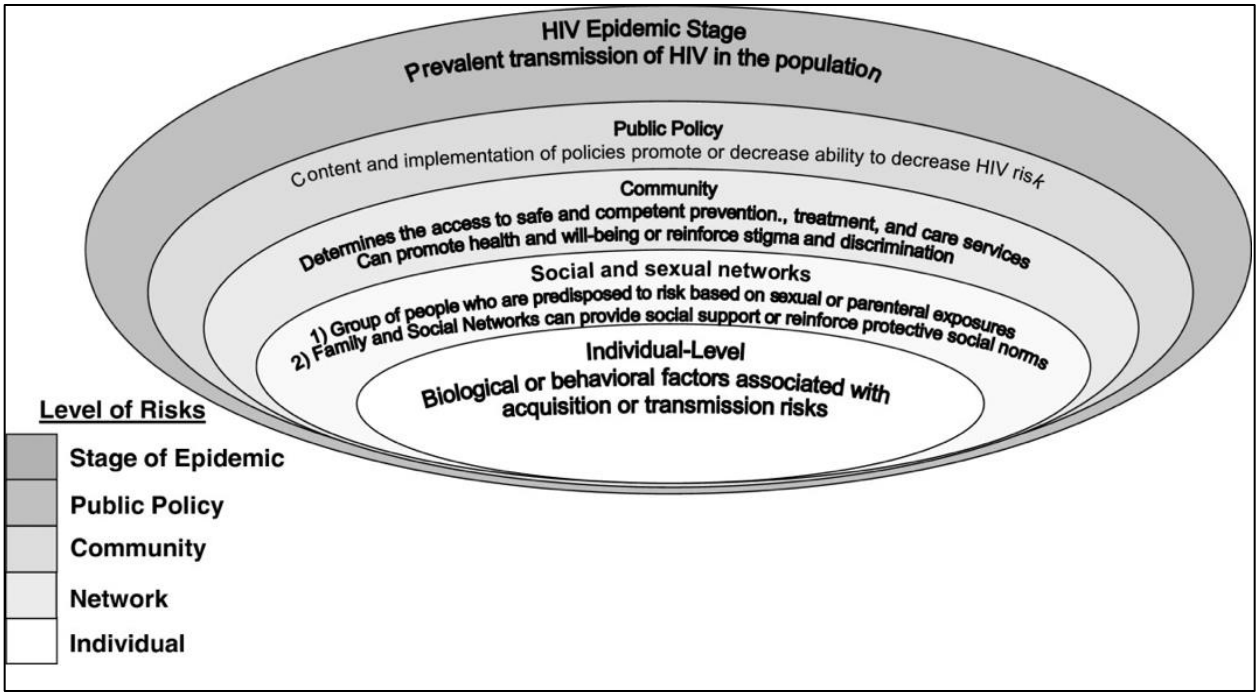


**Figure 1. Modified social ecological model.**

Described by Baral et al. (2013).[29]

### 3.2. Study design

The current study can be broken down into its two objectives and their respective methodologies. Objective 1 consisted of a narrative review, and Objective 2 consisted of molecular epidemiological analyses of cross-sectional, secondary data. The narrative review for Objective 1 served as a basis for understanding and contextualizing the molecular analyses in Objective 2. Given the separate study objectives and their respective designs and methodologies, the remainder of the methods section is organized by each objective.

### 3.3. Methods – Objective 1

Sukhera proposes five foundational elements to include when conducting a narrative review, to aid in a critical appraisal of the review's quality.[100] These five elements are: i) rationale; ii) clarity of boundaries, scope, and definitions; iii) justification for inclusion and exclusion criteria; iv) reflexivity and a saturation statement; and v) details on analysis and interpretation. Objective 1's methods and results were organized according to these elements.

#### 3.3.1. Rationale for review

The first element is intended to provide framing of the research question, specify the target audience, rationalize a narrative review as the method, and describe any iterative refinements to the initial research question.[100] Nigeria's HIV context, including those surrounding key populations, was described in the literature review preceding this methods section. Despite growing recognition of structural and social barriers faced by key population members, no narrative synthesis has examined the multi-level determinants of HIV service engagement among all key populations in Nigeria, nor has attention been paid to each respective group and their

geopolitical zones. The research question intended to be answered by Objective 1's narrative review was described in the research questions preceding this methods section. In brief, its initial research aims were to better understand the determinants influencing a) HIV acquisition and transmission; and b) programme utilization among key populations in Nigeria. Given that this question sought to describe and understand factors influencing HIV transmission events and engagement with existing programme services, the intended audience are those involved in the prevention, testing, and treatment of HIV in Nigeria, whether related directly to its delivery, or policy surrounding such work.

A narrative review was selected because of its ability to pull many pieces of information into a readable format, offering flexibility when encountering heterogeneity in outcomes, study designs, and populations.[101] In using this narrative method, the review presented a broad perspective and description of the last 20 years of the Nigerian HIV epidemic among key populations, in addition to its management and responses. Additionally, since Objective 1 was intended to inform Objective 2, a narrative review was best suited to generate a rich and comprehensive summary of HIV among Nigeria's key populations to contextualize findings of the molecular epidemiological analyses, in addition to being feasible and practical.[100]

It was revealed that initial database searches for Objective 1's research question yielded a large volume of records that persisted during full-text screening and threatened the feasibility for a single reviewer. Therefore, to ensure the Objective's feasibility while maintaining analytical rigour, the scope of the review was refined to focus on the determinants influencing HIV service and programme utilization (i.e., aim B) of the original research question. This refinement was implemented during full-text screening. While the revised research question emphasizes HIV programme access and utilization, such interventions are intrinsically linked to acquisition and

transmission events through their ability to modify awareness, beliefs, attitudes, and changes in behaviour.[102]

### 3.3.2. Clarity of boundaries, scope, and definitions

The second element defines the topic and research question(s), in addition to a description of changes made to the initial scope of the review.[101] For the purpose of this review, "key populations" referred to four of the five groups identified by the World Health Organization (WHO) as facing elevated HIV risk and disproportionate social and legal vulnerability: FSW, MSM, PWID, and transgender people.[103] Incarcerated people were not included, as they were not included in the 2020 Nigerian IBBSS which is the source of Objective 2's data. While the IBBSS utilized its own operational definitions for key population membership, outlined in Objective 2's methods section, this review considered any literature containing people who self-identified or were classified as FSW, MSM, PWID, or transgender people in the context of each respective study.

Programme utilization was defined as a tangible, measurable interaction with HIV prevention, testing, or treatment services. This included uptake, initiation, retention, or adherence. This definition intentionally excluded attitudinal or hypothetical outcomes (i.e., willingness, acceptability, or perceived need), as the aim of the Objective was to determine determinants actively affecting HIV programme service utilization.

The modified social ecological model was selected as the organizing framework because of its ability to capture determinants operating across multiple levels of influence (e.g., individual, network, community, and policy level).[29] Each level of the framework is defined and operationalized in Table 1. The epidemic stage level of the framework was excluded, as it does not correspond to a measurable exposure that could be extracted and compared between

individual studies. Additionally, given that Nigeria's HIV epidemic is defined as being mixed,[3] it was assumed that the four key populations examined in this review experience a high prevalence of HIV, making it a shared, fixed feature across these study populations.

**Table 1. Modified social ecological model classification scheme**

| **Framework level** | **Concept** | **Examples** |
|---|---|---|
| *Individual* | The determinant involved an individual's characteristics, perceptions, or behaviours. E.g., demographics, knowledge, beliefs, personal experiences. | Age, education, condom use, drug use, economic instability, key population group, fear of healthcare, anticipated stigma, internalized stigma, perceived HIV risk, HIV knowledge, testing history. |
| *Network* | The determinant involved an interaction with partners, peers, or family E.g., relationship dynamics, peer norms, social support. | Partner encouragement to test, status disclosure to partners/peers/family, social support, network size/density, network STBBI prevalence, client load. |
| *Community* | The determinant involved the healthcare or community setting where services are delivered. E.g., HIV service access/availability, provider behaviour, experiences of stigma in healthcare settings. | Residence (city, zone, urban vs. rural) geographical distance to clinic, disclosure to healthcare provider, provider stigma/discrimination, confidentiality concerns, transportation fees, service fees, public/private hospitals. |
| *Policy* | The determinant involved a law, policy, or structural system shaping service access. E.g., legal environment, national policies, funding structures, criminalization. | Criminalization of same-sex behaviour, legality of needle exchange, minimum prevention package intervention (MPPI) delivery by state/zone and/or key population group. |

### 3.3.3. Justification of inclusion and exclusion criteria

Specific inclusion and exclusion criteria are detailed in Table 2. Studies had to be situated in Nigeria, given the intent of this review to inform Objective 2. A publication date range from 2005 to 2025 (inclusive) was applied to align with the implementation of Nigeria's national ART treatment programme in 2001, for which HIV user fees were removed in 2005, at which time treatment delivery was also decentralized from federal medical centres to state hospitals.[38] Only primary and secondary studies published in English were eligible. Systematic reviews, conference abstracts, and protocols were excluded. Given feasibility concerns regarding peer-reviewed literature alone, it was determined that the review would only search the grey literature for policy-level determinants.

Studies were required to include at least one or more key population groups, although it was acceptable if findings across multiple key population groups were consolidated within the results. Studies were required to measure determinants (barriers or facilitators) with respect to a tangible HIV programme experience or outcome, such as service uptake, satisfaction, initiation, retention, and/or adherence to a service. HIV services included prevention (e.g., condoms and lubricants, PrEP, harm reduction, treatment as prevention or TasP), testing, and ART.

The initial search was developed using the University of Manitoba Libraries' search strategy worksheet (© 2024 Margaret Banka). In brief, the worksheet follows the following steps: i) indicate research question; ii) select a database(s); iii) identify the main concept(s), iv-a) generate synonyms for each concept; iv-b) generate subject headings for each concept; v) run a search; vi) apply filters; and vii) take notes. The main four concepts identified were: "Nigeria", "Context", "HIV program", and "Key Population". These concepts, following generation of synonyms, were mapped to appropriate subject headings to begin building each search concept.

The specific databases were chosen based on their relevance to health research and included Scopus, CINAHL (via EBSCO), MEDLINE (via OVID), Embase (via OVID), and Global Health (via OVID). Search strategies were modified within each database for compatibility, with translations guided by the TERA accelerator (https://tera-tools.com). Appendix C describes the search strategy used for each database. Search results were exported into RIS files and uploaded into Covidence to organize and record the screening process, perform deduplication, and generate a data extraction tool.[104]

**Table 2. Inclusion and exclusion criteria for narrative review.**

| Inclusion Criteria | Exclusion Criteria |
|---|---|
| Studies published between 2005 to 2025 (inclusive). | Studies published prior to 2005 or after 2025. |
| Studies published in English. | Studies not published in English. |
| Primary or secondary study. | Systematic reviews, conference abstract, or protocols only. |
| Studies that occurred in Nigeria. | Studies that occurred outside Nigeria or results not stratified by country. |
| Studies that included at least one key population group. | Studies that did not contain a key population group. |
| Studies where the outcome was related to an HIV service i.e., prevention (condoms, lubricants, harm reduction, PrEP) uptake of/adherence to a service, testing, and ART. | Studies that do not include an outcome related to an HIV service (e.g., general healthcare access). |
| Study where the outcome was explicitly tied to HIV service engagement (e.g., uptake, satisfaction, initiation, retention, and/or consistent adherence to a service). | Studies where the outcome was not related to tangible service uptake (e.g., attitudes, feasibility, acceptability, willingness). |

#### 3.3.4. Reflexivity statement and saturation

Since this review was conducted by a single researcher, there was potential for bias, as the author's perspective was expected to shape the selection and interpretation of literature. The data collection, analysis plans, and interpretation of this review have been inherently influenced by my positionality as the researcher leading this work. As a White, settler woman working within a Canadian academic institution, I recognize the contrast between my own social position and the lived realities of key populations affected by HIV, including, but not limited to, systematic barriers to healthcare, criminalization, and marginalization.[100] As an external reviewer

synthesizing community-generated evidence, there was risk of extracting knowledge that does not accurately convey the experience of the populations represented.

To mitigate this, the search strategy was developed in accordance with a protocol established by a research librarian and applied across the five databases described previously. This string was kept broad, and filtering was applied during title and abstract screening and confirmed during full-text review, rather than through iterative searching. Inclusion and exclusion criteria were defined and documented, and the classification scheme outlined in Table 1 was developed and documented prior to data extraction. Saturation was considered achieved when full-text screening of the final article set did not yield determinant categories that fell outside those already identified.

#### 3.3.5. Data extraction

Data extraction was carried out following an extraction template built in Covidence and displayed in Figure 2. While narrative reviews lack standardized guidelines, this review incorporated elements reported in alignment with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses Extension for Scoping Reviews (PRISMA-ScR)[105] to enhance methodological rigour.

Extracted information included the lead author, publication year, study period, location (collapsed into geopolitical zone), key population(s), and the determinants discussed as a facilitator or barrier to tangible HIV programme utilization. These data were then compiled into a long-format spreadsheet, with one row per determinant. Each determinant was assigned to a level of the modified social ecological model based on how it was operationalized and described in the source study to ensure consistency across studies. For quantitative studies, determinants had to reach statistical significance (e.g., in chi-square, unadjusted or adjusted regression

models) so that their influence as facilitators or barriers could be directly inferred based on the direction of the reported statistic. For qualitative studies, determinants had to be explicitly described as serving as a facilitator or barrier within the study. This was recorded in the data extraction by describing the influence of determinants as being "associated with" or "described as". Extracted determinants were grouped thematically within each level of the framework along with their influence as a facilitator or barrier. Where relevant, observations of divergence according to key population group and geopolitical zone were noted.

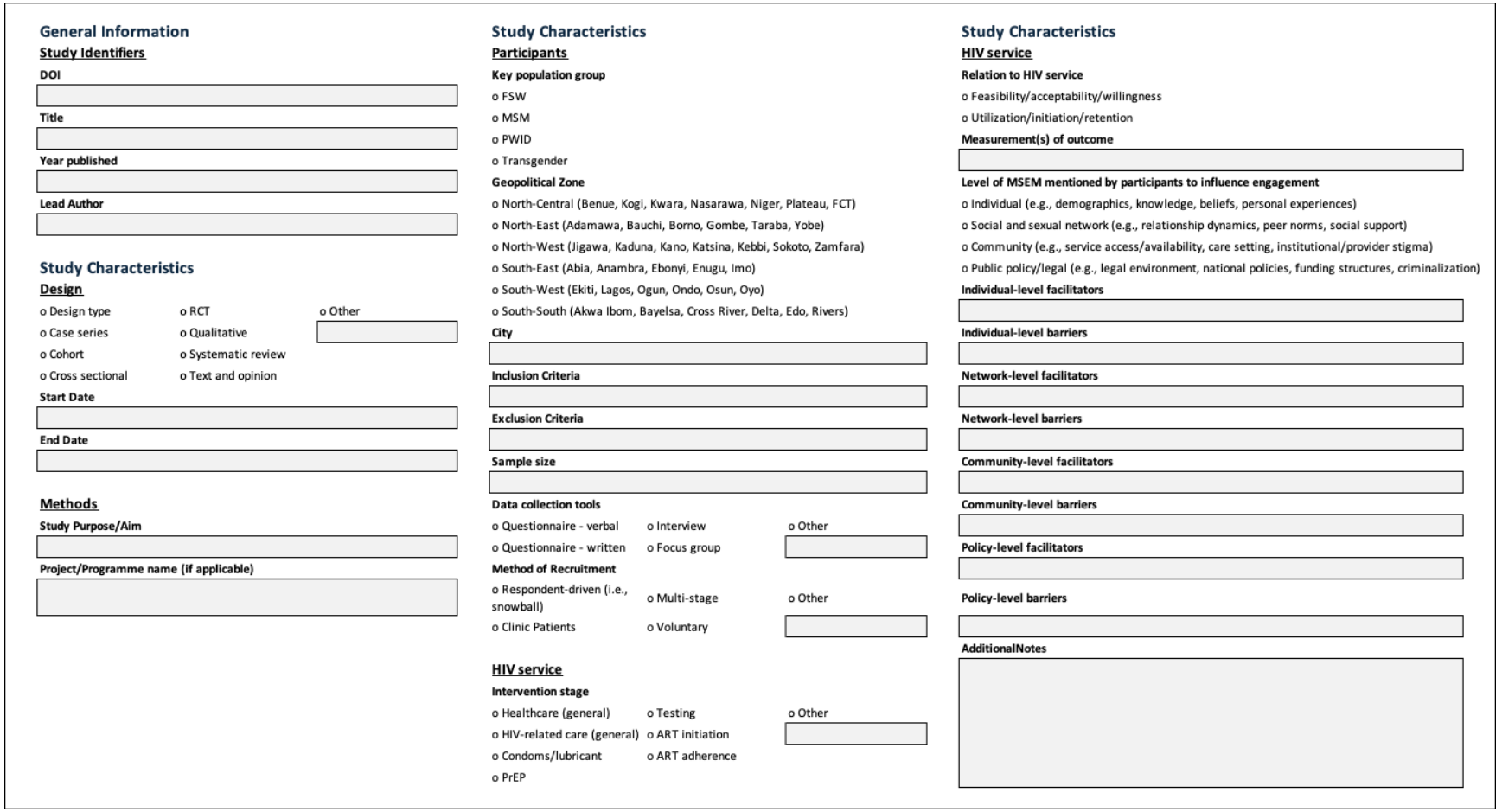


**Figure 2. Covidence data extraction template**

## 3.4. Methods – Objective 2

### 3.4.1. Study design

A quantitative, secondary analysis was carried out utilizing cross-sectional survey data conducted in Nigeria across four key populations: FSW, MSM, PWID, and transgender. Cross-sectional studies are suitable for assessing HIV prevalence, behaviours, patterns, and molecular characteristics using data collected from a single point in time, such as questionnaires and biological samples. It should also be highlighted that, in alignment with programme science principles of collaboration and consultation, the concept and research questions that guided this molecular analysis originated from the Institute for Global Public Health (IGPH)'s partnerships with NACA and the West African Centre for Public Health and Development (WACPHD), both of which are situated in Nigeria. The IGPH served as a technical partner for the 2020 IBBSS.

### 3.4.2. Study setting

The fourth Nigerian IBBSS took place from August to December 2020 across all the country's geopolitical zones. Nigeria's segmentation into six geopolitical zones is based on culture, ethnic groups, and history.[106] Nationally, social, cultural, economic, and geographical diversity is common and is reflected in disease patterns, health resource availability, and health outcomes.[106] Nigeria's developmental challenges are evident by low income per capita and significant disparities by income, gender, and education, which generally deepen moving from southern to northern regions.[32] The country's northern geopolitical zones are generally considered to have lower access to healthcare services, attributed to limited transportation, staffing, health provider conduct and attitude, and education levels.[32] Further, ongoing conflict and general political instability in northern Nigeria have been cited as causing mass internal displacement and disrupting healthcare and other activities.[107] Two states were collected from each zone for the

IBBSS, comprising a total of 12 states: North-East (Taraba and Gombe), North-Central (Benue and Nasarawa), North-West (Kaduna and Kano), South-East (Abia and Anambra), South-West (Lagos and Oyo), and South-South (Akwa Ibom and Rivers). Study states and their corresponding geopolitical zones are illustrated geographically in Figure 3. Within each zone, one state with a high prevalence and one with a low prevalence were selected based on previous literature and IBBSS rounds.[16]

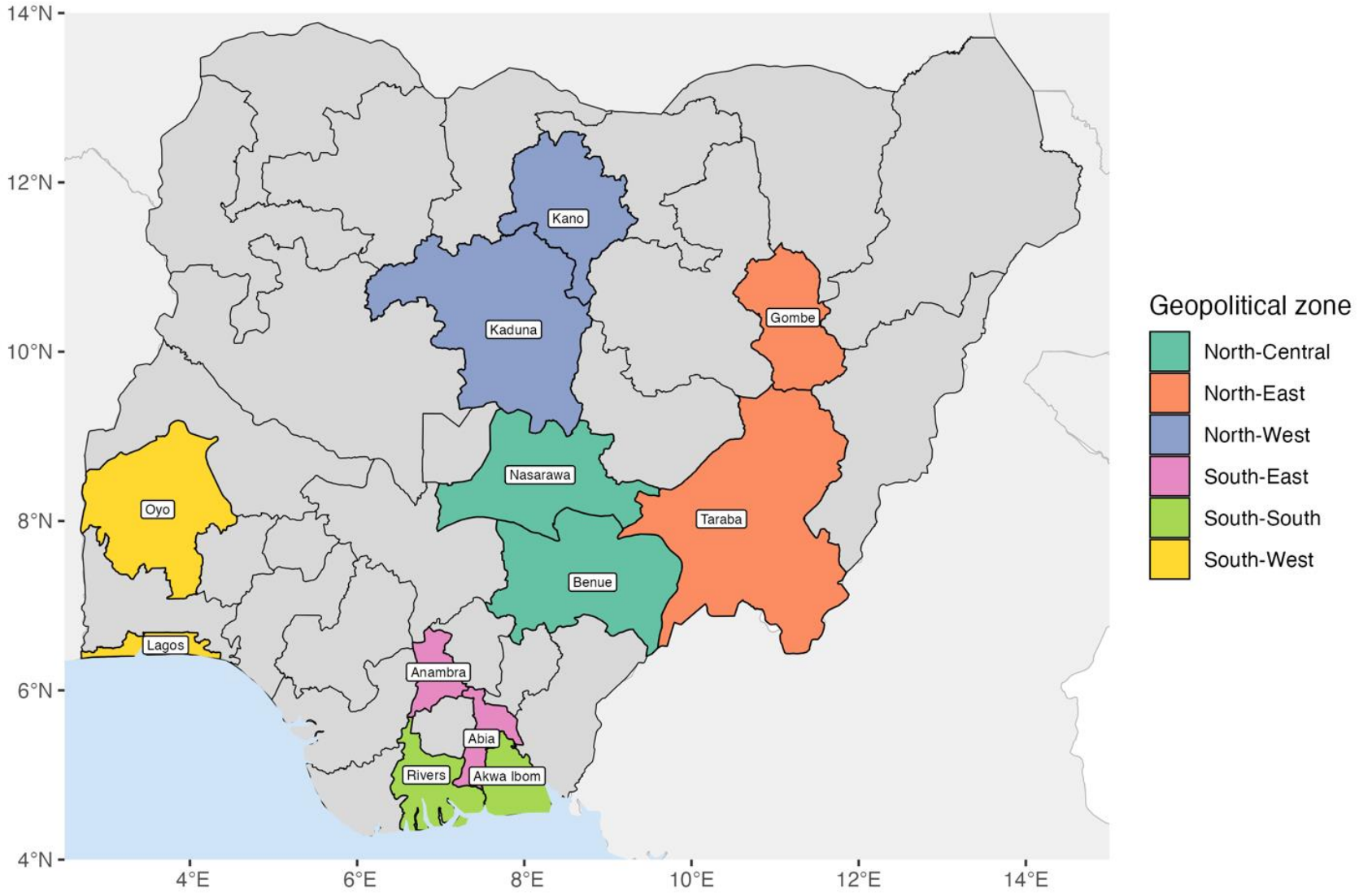


**Figure 3. States sampled per geopolitical zone; Nigerian IBBSS (2020)**

### 3.4.3. Sampling methodology

The sampling frame was determined based on previous location ("hotspot") mapping and size estimation studies, which generated a list of locations.[9, 108] Location typology refers to the types of locations where people from key populations congregate. A multi-stage sampling approach was employed, involving: 1) stratifying the location list by local government area and key population counts, then randomly selecting a fixed number of locations, and 2) randomly selecting participants in proportion to location typology size.[109] Field teams, including one key population peer member, visited selected location typologies at random times to identify and recruit participants.[16] Eligibility criteria included being aged 15 years or older and having engaged in sexual practices or injection drug use within the past month.[109]

The IBBSS required 370 participants per key population group in each state to ensure the detection of a 15% change in baseline risk behaviours from the previous 2014 IBBSS at a 95% significance level and 80% power.[16] The final sample size of the 2020 IBBSS was 17,975 participants, comprising 4,974 FSW, 4,397 MSM, 4,414 PWID, and 4,190 transgender participants.[16] Verbal informed consent was obtained for both biological and questionnaire components of the IBBSS. Participants were reimbursed 1,500 Naira (approximately 4 USD) for their time and travel costs related to the survey.

Respondents were categorized into key population groups based on self-reported sexual and/or injecting practices in the 12 months before the survey was conducted. Operational definitions used were: FSW—assigned female at birth and had received money or gifts in exchange for sexual services; MSM—identified as male and engaged in anal sex with another man; PWID— injected drugs recreationally at least once; and transgender—self-identified as

transsexual (i.e., a gender identity different from sex assigned at birth) and undertook sexual activity with a man. [9]

The IBBSS gathered data pertaining to sociodemographic characteristics, sexual and injecting behaviours, and the availability and utilization of HIV prevention, testing, and treatment services.[110] During initial data collection, all participants were assigned a study ID number. Only this study ID was associated with the dried blood spot specimens and questionnaire data to provide a link between each participant's specimen and questionnaire data. A structured behavioural electronic-based questionnaire was administered consisting of closed-ended questions. Study data collected in the questionnaire were stored on the IGPH server, for which OneDrive was used for sharing working copies of anonymous, de-identified datasets among study personnel. Following the questionnaire, participants underwent HIV rapid antibody testing and were linked to support services as needed, before those identified as HIV-reactive had a DBS specimen collected.

### 3.4.4. Questionnaire cleaning and recoding

As described above, a total of 17,975 participants took part in the 2020 IBBSS. Four key population spreadsheets extracted from the 2020 IBBSS were linked to an HIV viral load laboratory dataset and to the list of study IDs contained in phylogenetic clusters. Cross-data linkages were enabled by a study UID (subsequently referred to as "ID") code, formatted as: NG-XX [state abbreviation]-YY [local government area]-## [key population group]-### [ID].

Initial cleaning corrections were required across the databases to align with the correct state prefixes ("RI" to "RV" and "KN" to "KA") and replacement of forward slashes with hyphens to ensure a uniform delimiter between prefixes. The third prefix, local government area,

was removed to match DBS specimens IDs, which never contained this prefix upon shipment receipt.

Data cleaning steps are presented visually as supplementary material (Appendix F, Figure S1). In brief, each key population questionnaire dataset contained a small number of duplicate participant IDs, possibly arising from collapsing the local government area prefix. Following initial ID de-duplication, 17,810 questionnaires remained of the initial 17,975. Records with an HIV-seronegative (n=15,096) or a missing HIV rapid test results (n=19) were then removed, leaving behind 2,675 HIV-seropositive records. Linkage with HIV viral load data was made by inner-joining to the deduplicated HIV-seropositive questionnaires, yielding 2,279 linked records, of which 719 (31.5%) were identified as HIV viremic (viral load ≥1,000 copies/mL).

Following all dataset linkages, a consistent recoding scheme was applied to produce categorical variables that were suitable for descriptive and regression analyses. Viral load measures were rewritten into three groups (<10,000, 10,000-49,999, and ≥50,000 copies/mL). The recoding of the sociodemographic variables was as follows. Age was grouped into four bins (<25, 25-29, 30-34, ≥35 years). Education was collapsed into two levels (less than tertiary and tertiary). Marital status was initially collapsed from five source categories to three (single, currently married, divorced/separated/widowed), which was then further collapsed to two (single, non-single) to maintain sufficient sample size among groups in the non-single category. Employment was grouped into three categories (employed full- or part-time/other, unemployed, student/retired/unknown).

IBBSS respondents were assigned a location typology based on the location where participants were recruited for the survey, which was recoded into three venue types: 1)

Nightlife/sex venues (bar/night club/casino, brothel, massage parlour); 2) Residential/private (hotel/lodge, home, bunks); and 3) Street/virtual/other (street/public place, cemetery/abandoned building, trailer park/transport stop, beach/recreation park, eatery/shopping mall, sport centre, hostel/campus, virtual, other).

Proxies for programme coverage dimensions relevant to HIV testing were selected from IBBSS questions and informed by McClarty et al.[109] These included three of the four coverage domains: availability, outreach, and utilization. Programme availability was defined as "Knows of a health facility or place in their community where one can receive counselling and testing for HIV". Programme outreach was defined as "Contacted by a peer educator or by an outreach worker to provide HIV/AIDS-related services in the past year". Programme utilization was defined as "Received most recent HIV test in the past year". The three programme-related variables were recoded as Yes/No/No Response.

### 3.4.5. HIV sequencing and subtyping

All DBS were shipped to the National Sexually Transmitted and Blood Borne Infection Laboratory (Public Health Agency of Canada, Winnipeg, Canada) for subsequent analysis. Confirmatory HIV serological testing was performed using the AVIOQ HIV Micro Elisa System (Avioq Inc., Durham, NC). HIV RNA was quantified using the Aptima HIV Quant Dx assay (Hologic, Mississauga, Canada) and Panther system (Hologic) according to the manufacturer's instructions for DBS specimens. A viral load value of ≥1,000 copies/mL was classified as viremic, while <1,000 copies/mL was considered suppressed.[111, 112] Sequencing was attempted on all viremic samples.

Nucleic acid was isolated from a single DBS punch (1×12 mm) using a NucliSENS easyMAG (bioMérieux) according to the manufacturer's protocol for whole blood. Purified

nucleic acid was eluted in 50 µL of NucliSENS Extraction Buffer 3 (bioMérieux) and stored at -80°C until further processing. A 1,051-base portion of the HIV *pol* gene (positions 2253–3303 on HXB2, accession no. K03455) was amplified using a validated in-house HIV drug resistance genotyping assay.[113-115] MiSeq sequencing templates were prepared using Illumina Nextera XT DNA Library Preparation Kit (Illumina, San Diego, California, USA). Up to 96 libraries were pooled per MiSeq sequencing run with a 5% spike-in of PhiX Control v3 library (Illumina). All steps of the library preparation were performed using an epiMotion 5075t liquid handling workstation (Eppendorf, Hamburg, Germany). Sequencing was conducted on an Illumina MiSeq platform with the MiSeq Reagent Kit v2 (300-cycles; Illumina) according to the manufacturer's instructions.

HyDRA Web (http://hydra.canada.ca), an open-source pipeline for analyzing next-generation sequence (NGS) data, was used to perform quality filtering, mapping to HXB2, and generate consensus sequences as previously described.[113] HIV subtyping was performed before both sub-analyses by maximum-likelihood tree reconstruction in IQ-TREE v2.2.0.3[116] using the automatic best-fitting substitution model with the HIV Group M (subtypes A-K and recombinants) consensus alignment and previously genotyped Nigerian HIV pol sequences from the Los Alamos National Laboratory HIV database (LANL HIV DB) (https://www.hiv.lanl.gov/). Tree topology was supported by ultra-fast bootstrap (UFBoot)[117] resampling with 100,000 replicates and Shimodaira-Hasegawa-like approximate Likelihood Ratio Test (SH-aLRT)[118] with 1,000 replicates, where SH-aLRT ≥80% and UFBoot ≥95% were considered significant for clade assignment. Any sequences with insufficient node support were confirmed using the REGA HIV automated subtyping tool v3[119] and Stanford HIVdb programmev9.6,[120] if both tool assignments agreed.

### 3.4.6. Phylogenetic clustering

Reference sequences were collected for each subtype of recovered sequences. This included the above mentioned pre-genotyped LANL HIV DB sequences. Identification numbers for sequences obtained from the LANL HIV DB are provided as supplementary material (Appendix E, Table S5). Manual sequence alignment was performed in AliView.[121] Prior to phylogenetic tree building, codons associated with drug resistance mutations (DRMs) were masked from study and reference sequences.

For each subtype, maximum-likelihood tree reconstruction was performed in IQ-TREE v2.2.0.3[116] using the automatic best-fitting substitution model and UFBoot re-sampling with 100,000 replicates. Phylogenetic clusters were inferred by tip-to-tip (patristic) distance between sequences on phylogenetic trees. A distance threshold of <0.02 (i.e., 2%) substitutions per site and >50% bootstrap support was used to infer transmission clusters.[20] Clusters were visualized and annotated using questionnaire data in ggplot2.[122]

#### *3.4.6.1. Statistical analysis*

The list of clustering sequence IDs was inner-joined to restrict each dataset to participants for whom an HIV protease sequence was available, yielding 547 (76.1%) recoverable sequences from viremic specimens with a linked questionnaire. The primary outcome was membership in phylogenetic clusters as a binary variable (clustering versus non-clustering), based on the above distance threshold and tree support values. Sociodemographic characteristics used as predictor variables include age at enrollment, key population group, geopolitical zone, education level, marital status, employment status, and location typology. Sex or gender variables were not included in the model given the overlap with operational key population definitions. Programme engagement variables used as predictor variables included knowledge of a place to receive

HIV/AIDS counselling and testing, contact by an outreach worker in the past year, and received most recent HIV test within the past year.

Descriptive statistics were calculated for the sociodemographic, behavioural, and virological characteristics stratified by membership in phylogenetic clusters (yes/no). Pearson's chi-square test was applied to evaluate the associations between presence in phylogenetic clusters and predictor variables using the stats package in R v4.4.2 (2024-10-31).[123] For the regression analyses, associations with the primary outcome variable, membership in phylogenetic clusters, were assessed with generalized linear models using a Poisson distribution with robust standard errors and log link to approximate unadjusted and adjusted prevalence ratios (PRs and aPRs, respectively) and 95% confidence intervals (95% CI). Modified Poisson regression was selected over logistic regression because clustering was common in the sample (25.9%) and odds ratios would overstate associations. A p-value $<0.05$ was considered statistically significant.

All sociodemographic and programme engagement variables (i.e., no virologic characteristics) were included in the multivariable model as predictors because of their established relevance to HIV transmission risk and programme engagement, as confirmed through the narrative review in Objective 1. Non-response to programme variables were retained as a category to preserve the full sample of 547, as complete-case analysis would have reduced the sample by 111 (20.3%) participants. Further, model estimates shifted when non-responses were retained or excluded, suggesting that non-response was non-random. These categories were not interpreted as exposures. Multicollinearity among covariates was assessed using generalized variance inflation factors (GVIF), with $GVIF^{(1/(2*df))}$ used to allow comparisons across terms with different degrees of freedom.

### 3.4.7. Phylodynamic modelling

Phylodynamic modelling was conducted by a Bayesian MCMC analysis of time-stamped HIV protease sequences collected during the IBBSS in BEAST v2.7.5,[82] and results were visually analyzed and processed using BEAST_pype's diagnostic tools (https://github.com/m-d-grunnill/BEAST_pype/wiki).

Analyses were limited to HIV subtypes CRF02_AG and G from the sequence dataset, since these strains reflect the dominant HIV subtypes within the study and circulating in Nigeria.[124] Duplicate sequences from both HIV subtypes (n=5 from subtype CRF02_AG; n=2 from subtype G) had to be removed to prevent polytomy of tips. Polytomy is defined as a node with more than two lineages descending from a single ancestral lineage, which have been known to cause unpredictable behaviour in Bayesian analyses.[125] This produced a final sample size of 364 sequences classified as HIV subtype CRF02_AG and 139 sequences classified as HIV subtype G (Appendix E, Table S7).

Effective population sizes were inferred using a *Bayesian Coalescent Skyline Plot* tree prior.[30] A general time reversible (GTR) substitution model with four gamma categories and a strict molecular clock model with a log normal distribution (mean: 1.0, standard deviation: 1.25) were assumed, set to a mean clock rate of $2.5 \times 10^{-3}$ substitutions/site/year (lower bound: $1.0 \times 10^{-3}$, upper bound: $4 \times 10^{-3}$).[126] Chain lengths of 300,000,000 MCMC were sampled, generating 10,000 trees until an effective sample size (ESS) >200 was obtained in Tracer v1.7.2 for all statistics, suggesting acceptable mixing of parameters.[127] Parameter estimates were reported alongside their 95% highest posterior density (HPD) interval, corresponding to the shortest interval in parameter space that contains 95% of the posterior probability, which is somewhat analogous to a 95% CI.

The median number of ancestral migration events were inferred between the four key population groups, and between the six geopolitical zones, respectively. A structured coalescent approach was used following a *MultiTypeTree* prior.[83] As with the Bayesian skyline plot models, a GTR substitution with 4 gamma categories and a strict molecular clock with a log normal distribution (mean: 1.0, standard deviation: 1.25) was assumed, set to the respective clock rates generated from the posterior of the effective population size estimates described above (Appendix E, Table S8). Restrictions were set on population size ($log_{10}$) for each key population group and geopolitical zone, respectively, based on previous programmatic mapping exercises carried out in Nigeria (Appendix E, Table S9).[108, 128, 129] The same size estimates were used for both HIV subtypes. Parameter estimates were reported alongside their 95% HPD.

Findings from both types of phylodynamic models (Bayesian skyline plots and structured coalescent models) were contextualized using trends in HIV spending expenditure using the six rounds of National AIDS Spending Assessment reports conducted between 2007 to 2021,[130-135] and estimated key HIV indicators for Nigeria obtained from the AIDS Impact Model (AIM, https://aim.spectrumweb.org).[136] Expenditure data for which "most-at-risk populations" were the beneficiary comprised public, private, and donor financing, including government revenue, bilateral contributions, multilateral agencies, and international non-for-profit organizations, and captures total HIV/AIDS programme expenditure across prevention, treatment, and care.

# CHAPTER 4 RESULTS

## 4.1. Narrative Review – Objective 1

### 4.1.1. Overview of records

The search for literature across five databases produced a total of 1,065 studies. After duplicates (n=658) were removed, the title and abstracts of the remaining (n=407) studies were screened for relevance. Of the remaining studies (n=218) retained for full-text screening, 36 met the prespecified inclusion/exclusion criteria and were included in the narrative review. Studies were primarily excluded either because the reported outcomes were not related to an HIV service (e.g., general healthcare access vs. HIV prevention, testing, or treatment), or the outcomes were behaviours described in isolation, rather than programme engagement (e.g., condom use versus consistent engagement with a condom service). A PRISMA flow chart detailing this process is illustrated in Figure 4.

Characteristics of the 36 retained studies are presented in Table 3. Two grey literature sources were also included for their influence at a policy-level.[137, 138] Despite having inclusion criteria for studies dating back to 2005, publication years of the retained studies ranged from 2012 to 2025. Most records encompassed multiple key population groups, with MSM represented in the majority of retained studies (n=30/36, 83%), followed by FSW (n=15/36, 42%), transgender people (n=12/36, 33%), and PWID (n=10/36, 28%), shown in Figure 5. Most studies also included multiple sites covering greater than one geopolitical zone, as pictured in Figure 6. The North-Central (n=27/36) and South-West (n=24/36) zones were represented the most among retained studies. This was followed by the South-South (n=11/36), North-West (n=10/36), North-East (n=4/36), and South-East (n=4/36).

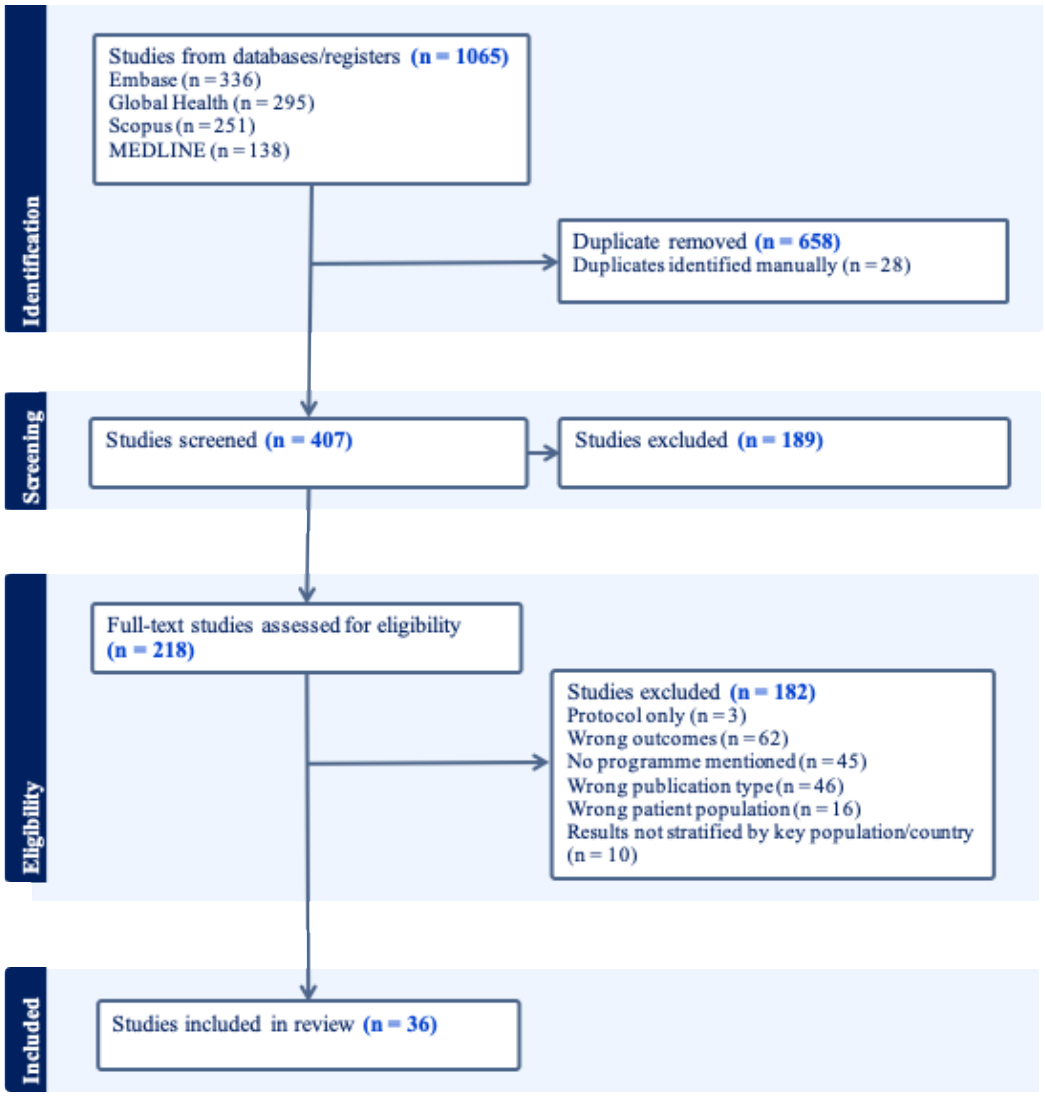


**Figure 4. PRISMA diagram.**

**Table 3. Characteristics of retained peer-reviewed studies in ascending date (n=36).**

| First author[citation] | Year | Title | Key population(s) | Geopolitical zone(s) |
|---|---|---|---|---|
| Stromdahl[139] | 2012 | Associations of consistent condom use among men who have sex with men in Abuja, Nigeria. | MSM | North-Central |
| Vu[140] | 2013 | High levels of unprotected anal intercourse and never testing for HIV among men who have sex with men in Nigeria: evidence from a cross-sectional survey for the need for innovative approaches to HIV prevention. | MSM | North-Central; South-West |
| Schwartz[40] | 2015 | The immediate effect of the Same-Sex Marriage Prohibition Act on stigma, discrimination, and engagement on HIV prevention and treatment services in men who have sex with men in Nigeria: analysis of prospective data from the TRUST cohort. | MSM | North-Central |
| Adebajo[141] | 2015 | Evaluating the effect of HIV prevention strategies on uptake of HIV counselling and testing among male most-at-risk-populations in Nigeria; a cross-sectional analysis. | MSM; PWID | North-Central; North-West; South-West |
| Charurat[142] | 2015 | Uptake of treatment as prevention for HIV and continuum of care among HIV-positive men who have sex with men in Nigeria | MSM | North-Central |
| Ibiloye[143] | 2018 | Characteristics and early clinical outcomes of key populations attending comprehensive community-based HIV care: Experiences from Nasarawa State, Nigeria. | FSW; MSM; PWID | North-Central |
| Ramadhani[144] | 2018 | Individual and Network Factors Associated With HIV Care Continuum Outcomes Among Nigerian MSM Accessing Health Care Services. | MSM | North-Central; South-West |
| Rodriguez-Hart[49] | 2018 | The Synergistic Impact of Sexual Stigma and Psychosocial Well-Being on HIV Testing: A Mixed-Methods Study Among Nigerian Men who have Sex with Men | MSM; Transgender | North-Central; South-West |
| Tun[145] | 2018 | Uptake of HIV self-testing and linkage to treatment among men who have sex with men (MSM) in Nigeria: A pilot programme using key opinion leaders to reach MSM | MSM | South-West |

| | | | | |
|---|---|---|---|---|
| Ogunbajo[146] | 2019 | Awareness, willingness to use, and history of HIV PrEP use among gay, bisexual, and other men who have sex with men in Nigeria. | MSM | North-Central; South-West; South-South |
| Ochonye[13] | 2019 | Satisfaction with use of public health and peer-led facilities for HIV prevention services by key populations in Nigeria. | FSW; MSM; PWID | North-Central; South-East; South-South |
| Emmanuel[147] | 2019 | HIV sexual risk behavior and preferred HIV prevention service outlet by men who have sex with men in Nigeria. | MSM | North-West; South-South |
| Crowell[148] | 2019 | Time to change the paradigm: limited condom and lubricant use among Nigerian men who have sex with men and transgender women despite availability and counseling. | MSM; Transgender | North-Central; South-West |
| Kayode[149] | 2020 | Retention of a cohort of men who have sex with men and transgender women at risk for and living with HIV in Abuja and Lagos, Nigeria: a longitudinal analysis | MSM; Transgender | North-Central; South-West |
| Ramadhani[150] | 2020 | Association of age with healthcare needs and engagement among Nigerian men who have sex with men and transgender women: cross-sectional and longitudinal analyses from an observational cohort | MSM; Transgender | North-Central; South-West |
| Balogun[151] | 2020 | Negotiating access to the Nigerian healthcare system: the experiences of HIV-positive men who have sex with men | MSM | North-Central; South-West |
| Afolaranmi[152] | 2021 | Retention in HIV care and its predictors among HIV-infected men who have sex with men in Plateau state, North Central Nigeria. | MSM | North-Central |
| Ibiloye[153] | 2021 | Long-term retention and predictors of attrition for key populations receiving antiretroviral treatment through community-based ART in Benue State Nigeria: A retrospective cohort study. | FSW; MSM; PWID; Transgender | North-Central |
| Olawore[154] | 2021 | Individual and partnership characteristics associated with consistent condom use in a cohort of cisgender men who have sex with men and transgender women in Nigeria. | MSM; Transgender | North-Central; South-West |
| Ibiloye[155] | 2021 | Community health worker-led ART delivery improved scheduled antiretroviral drug refill among men who have sex with men in Lagos State, Nigeria. | MSM | South-West |
| Tun[58] | 2022 | A qualitative study of how stigma influences HIV services for transgender men and women in Nigeria | Transgender | South-West |

| | | | | |
|---|---|---|---|---|
| Omo-Emmanuel[156] | 2023 | Assessment of awareness, willingness, and practice of Human immunodeficiency virus pre-exposure prophylaxis among female sex workers in Uyo, Akwa Ibom, Nigeria. | FSW | South-South |
| Ramadhani[157] | 2023 | Determinants of preexposure prophylaxis cascade among Nigerian MSM | MSM; Transgender | North-Central; South-West |
| Ibiloye[158] | 2024 | Realist evaluation of a community-based antiretroviral therapy (CBART) programme for key populations in Benue State in Nigeria. | FSW; MSM; PWID | North-Central |
| Nwosu[159] | 2024 | Factors associated with viral load testing and viral suppression among HIV-positive female sex workers in Nigeria. | FSW | North-Central; North-West; South-West; South-South |
| Ochonye[160] | 2024 | Pre-Exposure Prophylaxis and HIV Prevention Among Key Populations in Nigeria. | FSW; MSM; PWID | North-Central; North-West; South-West; South-South |
| Dirisu[161] | 2024 | 'I take the drugs... to make the sickness to move out of me': key populations' and service provider perspectives about facilitators and barriers to ART adherence and retention in care in Nigeria. | FSW; MSM | North-Central; South-West |
| Okonkwo[162] | 2024 | Barriers to Accessing Antiretroviral Treatment Among Key Populations in Southwest Nigeria. | FSW; MSM; PWID; Transgender | South-West |
| Olakunde[163] | 2024 | Prevalence and correlates of prenatal HIV testing among female sex workers in Nigeria | FSW | North-Central; North-East; North-West; South-East; South-West; South-South |
| Olakunde[164] | 2024 | Awareness and uptake of oral pre-exposure prophylaxis among adolescent and young key populations in Nigeria: a secondary data analysis of the 2020 Integrated Biological & Behavioural Surveillance Survey. | FSW; MSM; PWID; Transgender | North-Central; North-East; North-West; South-East; |

| | | | | |
|---|---|---|---|---|
| | | | | South-West; South-South |
| Sadiq[165] | 2025 | Correlates of HIV pre-exposure prophylaxis (PrEP) uptake among female sex workers in northern Nigeria. | FSW | North-West |
| Ogunbajo[166] | 2025 | Intersectional stigma and adherence to antiretroviral (ART) among sexual minority men (SMM) living with HIV in Nigeria: A Qualitative Inquiry. | MSM | South-West |
| Nwosu[167] | 2025 | Oral PrEP continuation rates among key populations in Nigeria: a retrospective cohort study of a large-scale HIV prevention programme. | FSW; MSM; PWID; Transgender | North-Central; North-East; North-West; South-West; South-South |
| Anyiam[168] | 2025 | HIV self-testing lived experiences of female sex workers in the Garden City, Eastern Nigeria. | FSW | South-South |
| Volpi[169] | 2025 | Impact of Age of Sexual Debut on HIV Care Engagement Among Sexual and Gender Minorities in Nigeria. | MSM; Transgender | North-Central; South-West |
| Emmanuel[12] | 2025 | Improving HIV Prevention for Key Populations in Nigeria: Insights on Access, Barriers, Stigma, and Service Utilization. | FSW; MSM; PWID | North-West |

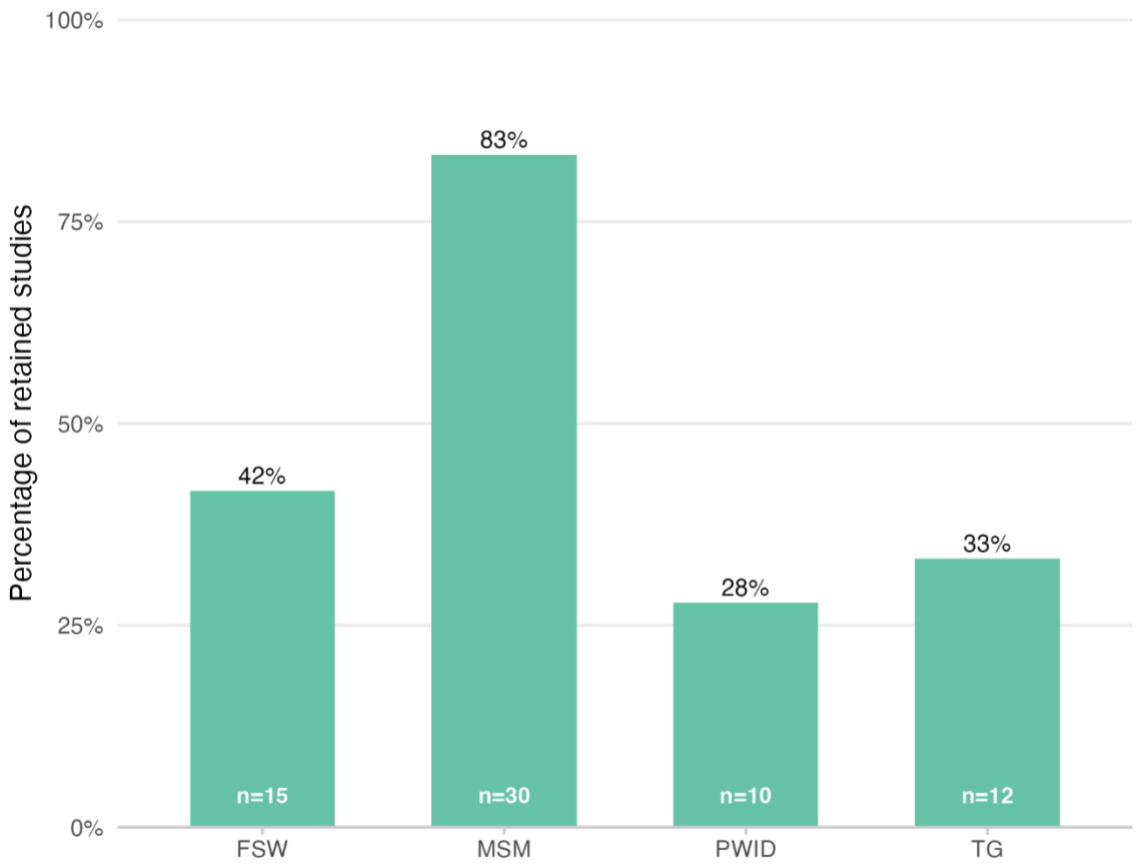


**Figure 5. Coverage of Nigerian key population group(s) among retained studies (n=36).**

Key populations stand for: Female sex workers (FSW), men who have sex with men (MSM) and people who inject drugs (PWID).

Most studies included multiple key population groups.

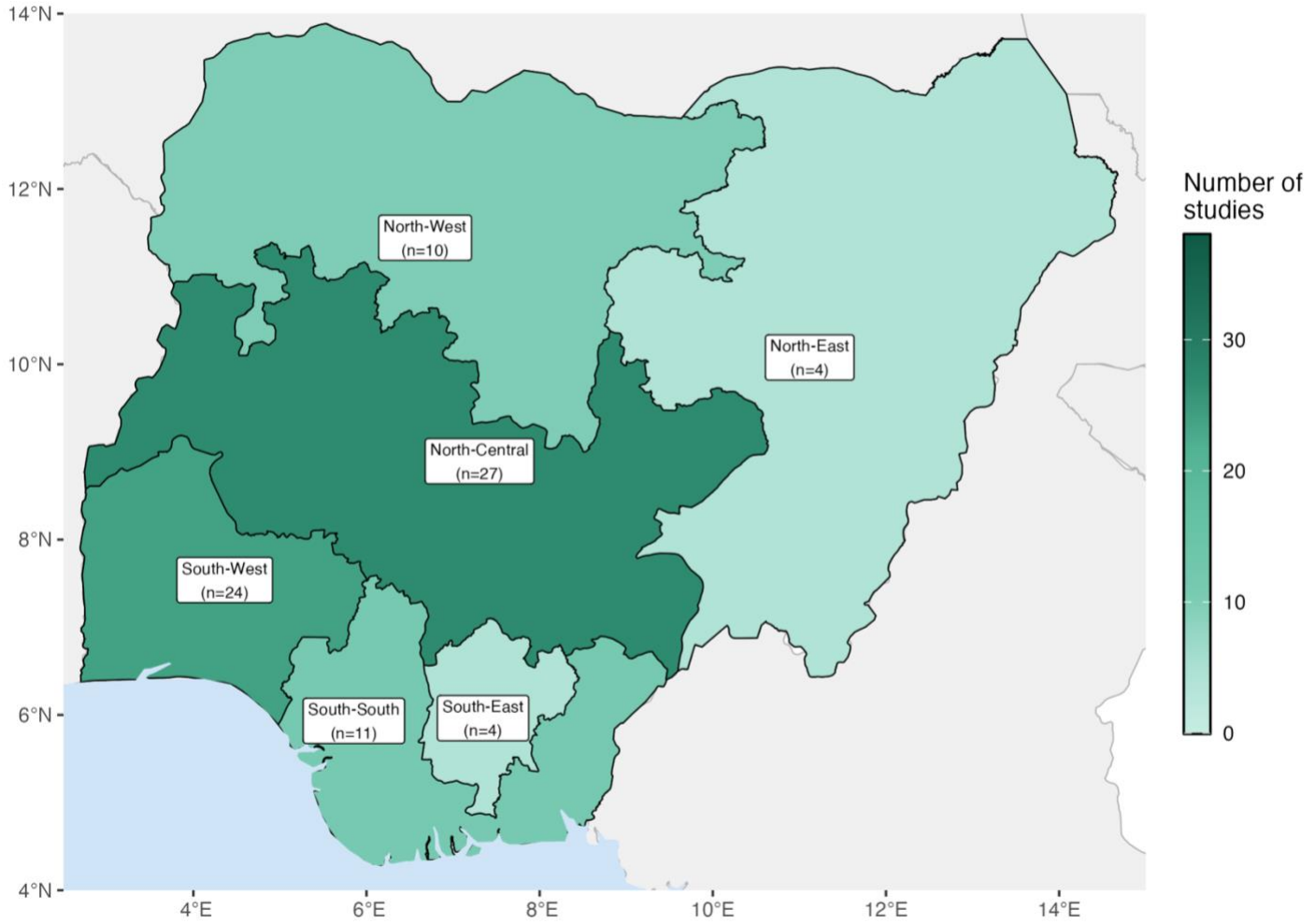


**Figure 6. Coverage of Nigerian geopolitical zones among retained studies (n=36).**

Most studies covered multiple sites that spanned multiple geopolitical zones.

### 4.1.2. Determinants associated with HIV service outcomes

The percentage of retained studies reporting individual-, network-, and community-level determinants by key population group inclusion is displayed in Figure 7. Among all key population groups, individual-level determinants were most frequently discussed. This was highest among retained studies which reported on FSW (93%, n=14/15), then transgender people (83%, n=10/12), PWID (80%, n=8/10), and MSM (77%, n=23/30). Community-level determinants were the next most frequent determinant described, across studies containing transgender people (67%, n=8/12), MSM (63%, n=19/30), PWID (60%, n=6/10), and lower among FSW (47%, n=7/15). Network-level determinants were least common, though more common among studies containing MSM (27%, n=8/30) and transgender people (25%, n=3/12).

Tables 4-7 describe extracted determinants at each level of the modified social ecological model for their effect on HIV service outcomes. Determinants are presented as being negatively associated/described as a barrier ("↓") or positively associated/described as a facilitator ("↑").

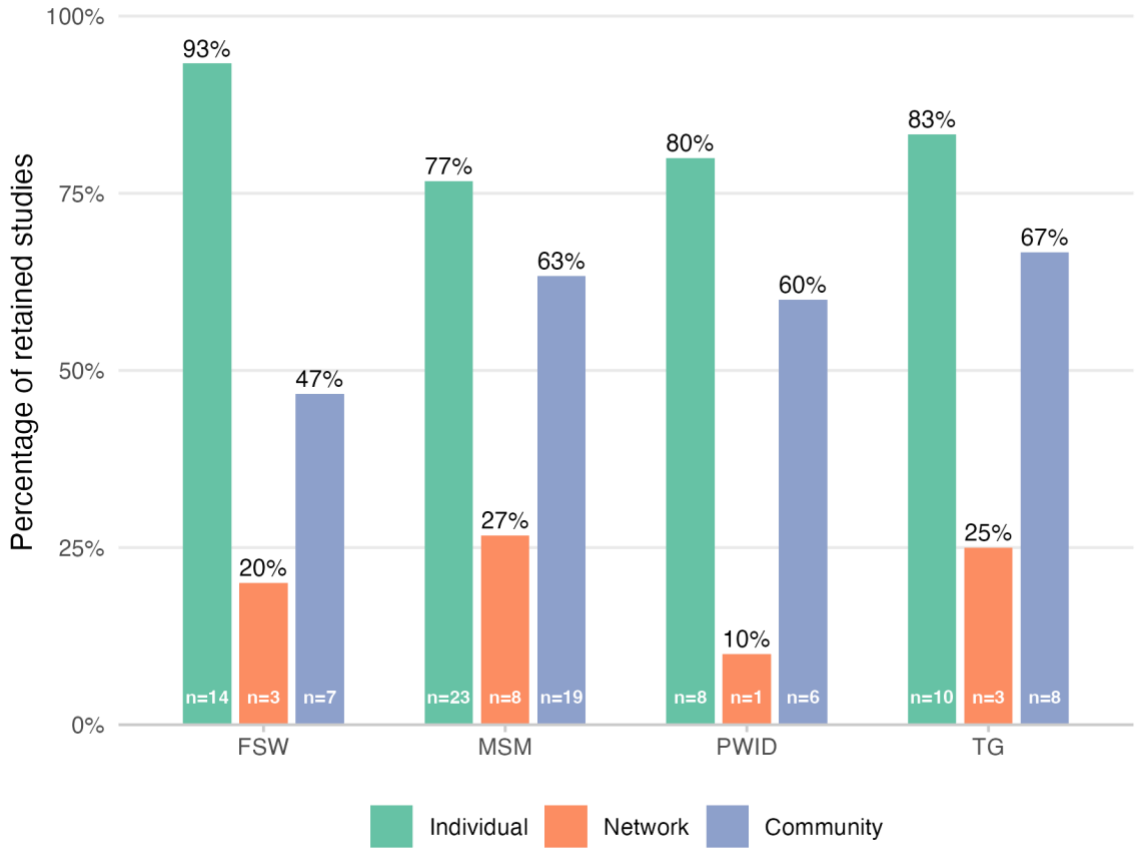


**Figure 7. Reporting of individual-, network-, and community-levels determinants among retained studies that included each respective key population group.**

Retained studies that included each key population group: FSW, n=15, MSM, n=30, PWID, n=10, and transgender people (TG, n=12). Most studies described multiple determinants at multiple levels of the modified social ecological model. The policy level is not pictured in the key population group breakdown, as determinants at this level typically carried implications for all key population groups.

#### *4.1.2.1. Individual level*

A range of individual-level determinants were associated with service outcomes across the HIV care cascade, as described in Table 4. Initial extraction of individual-level determinants on a per-

study basis and according to key population group(s) and geopolitical zone(s) are also provided (Appendix D, Table S1). Sociodemographic factors were most frequently linked to outcomes. Younger age was typically negatively associated with HIV programming outcomes across prevention,[148, 150, 154, 167] testing,[140, 144, 150, 169] and treatment domains,[144, 150, 153] while educational levels higher than senior secondary were almost always positively associated with HIV prevention,[139, 148, 154, 157, 167] testing,[140, 144, 149, 163, 169] and treatment.[143, 144, 159, 169] Not being employed was negatively associated with PrEP uptake[157, 164, 167] and positively associated with no history of HIV testing[140] and ART attrition.[143] Non-cisgender identity was described as a facilitator of viral suppression and maintaining visit adherence.[149, 169] Relative to FSW, membership in MSM or transgender key population groups were found to be facilitators of PrEP uptake[163] and continuation[160, 167] across multiple geopolitical zones, though MSM membership was also a facilitator of ART attrition in the North-Central zone.[153]

Previous HIV/STBBI programming history was also a frequently explored determinant. Having a history of being tested for HIV and other STBBIs were facilitators of condom use,[139, 154] while no HIV testing history was a facilitator of loss-to-follow-up in prevention services over 180 days and a barrier to maintaining visit adherence over three months.[149] Having HIV/STBBI and prevention knowledge was described as a facilitator to condom use,[139, 154] HIV testing,[144, 169] and achieving viral suppression,[169] and knowledge of PrEP was a facilitator to PrEP uptake.[146] Similarly, history of being treated for an STBBI was a facilitator of condom use[154] and PrEP uptake.[165] A positive HIV status was a facilitator of condom/lubricant use,[148, 154] while a negative status was a facilitator of no HIV testing history,[140] loss-to-follow-up,[40, 149] and a barrier to maintaining visit adherence over three months.[149] Programme enrollment factors influenced both prevention and treatment retention, with longer enrollment duration as a facilitator to consistent

condom/lubricant use[148] and enrollment in a TasP programme as a barrier to loss-to-follow-up after three months (i.e., a facilitator of retention).[142]

Sexual history, personal feelings when accessing care and day-to-day circumstances also emerged as important determinants. More specifically, a history of transactional sex was negatively associated with condom use,[139] PrEP uptake,[156] prenatal HIV testing,[163] ART uptake,[169] viral suppression,[169] and maintaining visit adherence,[149] in addition to being positively associated with loss-to-follow-up.[149] Fear, anxiety, or mistrust of healthcare services were negatively associated with condom and lubricant use,[154] and anticipated/internalized stigma were similarly negatively associated with HIV self-testing,[168] ART adherence,[166] and accessing HIV services.[166] Financial difficulty,[35, 146] schedule conflicts,[161] and transport fare[161] were all described as barriers to treatment or general HIV service access.

Findings were not always consistent across studies or key populations. Older age, for example, was sometimes positively associated with condom use (MSM and transgender people in North-Central and South-West zones)[148] and PrEP continuation (MSM and transgender people in North-Central and South-West zones; and all key populations in zones apart from the South-East),[157, 167] but negatively associated with condom use in another study (MSM and transgender people in North-Central and South-West zones).[154] While bisexual and non-homosexual sexual orientations were described as negatively associated with HIV testing (MSM in North-Central and South-West zones)[144] and maintained visit adherence (MSM and transgender women in North-Central and South-West zones),[149] it was also positively associated with ART uptake (MSM and Transgender people in North-Central and South-West zones).[169] Marital status was also an inconsistent determinant, with married status (FSW in the North-West zone)[165] and non-married (FSW in all six zones)[163] status described as facilitators to PrEP uptake among FSW in

different studies. Although having an HIV/STBBI programme service history was positively associated with condom use, HIV testing, and viral suppression across studies,[139, 144, 154, 169] it was also negatively associated with ART uptake (MSM and Transgender people in North-Central and South-West zones)[169] and adherence (FSW, MSM, and PWID in the North-Central zone).[158]

**Table 4. Individual-level determinants associated with HIV service outcomes among key populations in Nigeria.**

| Determinant | Care cascade step | Finding (↑=positively-associated, ↓=negatively-associated) |
|---|---|---|
| ***Sociodemographic factors*** | | |
| Age | Prevention | ↓ Receipt of HIV prevention information (younger age)[150]<br>↑ Condom/lubricant use (older age)[148]<br>↓ Condom use (older age)[154]<br>↑ PrEP continuation (older age)[157, 167] |
| | Testing | ↑ History of HIV testing (younger age)[144]<br>↓ History of HIV testing (younger age)[140, 150]<br>↓ History of HIV testing (earlier age of sexual debut)[169]<br>↑ History of HIV testing (older age)[169] |
| | Treatment | ↓ ART uptake (younger age)[144, 150]<br>↓ Viral suppression (younger age)[144]<br>↑ ART attrition/loss-to-follow-up (younger age)[149, 153]<br>↓ HIV service visit adherence (younger age)[149] |
| Sex | Prevention | ↓ PrEP continuation (male)[157, 167] |
| | Treatment | ↑ ART attrition (male)[153] |
| Gender identity | Prevention | ↓ Condom use (non-binary gender identity)[154] |
| | Treatment | ↑ Viral suppression (non-cisgender identity)[169]<br>↑ Visit adherence (non-cisgender identity)[149] |
| Sexual orientation | Testing | ↑ History of HIV testing (homosexual)[144]<br>↓ History of HIV testing (bisexual/non-homosexual)[169] |
| | Treatment | ↑ ART uptake (bisexual/non-homosexual)[169]<br>↓ Visit adherence (bisexual/non-homosexual)[149] |
| Formal education | Prevention | ↑ Condom use[148, 154 139]<br>↑ PrEP uptake/continuation[157] |

| | | |
|---|---|---|
| | Testing | ↑ History of HIV testing[144, 163, 169]<br>↑ No history of testing (no formal education)[140] |
| | Treatment | ↑ ART uptake[144, 169]<br>↑ ART attrition/loss-to-follow-up (no formal education)[143, 149]<br>↓ Visit adherence (no formal education)[149] |
| Employment status | Prevention | ↓ PrEP uptake/continuation (non-employed)[157, 164, 167] |
| | Testing | ↑ No history of testing (non-employed)[140] |
| | Treatment | ↑ ART attrition (non-employed)[143]<br>↑ Viral suppression (student) [159] |
| Marital status | Prevention | ↑ Condom/lubricant use (married/non-single)[148]<br>↑ PrEP use (married/non-single)[165]<br>↑ PrEP uptake (non-married)[163] |
| | Testing | ↑ History of prenatal HIV testing (married/non-single)[163] |
| ***Membership-based factors*** | | |
| Key population | Prevention | ↑ PrEP uptake (MSM, TG)[160, 163]<br>↓ PrEP continuation (MSM, TG)[157, 167] |
| | Treatment | ↑ ART attrition (MSM, TG)[153] |
| | Prevention | ↑ Short-term PrEP uptake (FSW, PWID)[160] |
| Religion | Prevention | ↑ PrEP use (Christian religion)[165] |
| | Prevention | ↓ PrEP uptake (Muslim/non-Chistian religion)[163] |
| | Treatment | ↓ ART uptake/TasP engagement (Muslim/non-Christian religion)[142, 144]<br>↑ Viral suppression (Muslim/non-Christian religion)[144] |
| ***HIV/STBBI factors*** | | |
| History of HIV/STBBI testing | Prevention | ↑ Condom use (previous HIV and STBBI testing)[139, 154] |
| | Treatment | ↑ Loss-to-follow-up (no HIV testing history) [149]<br>↓ Visit adherence (no HIV testing history) [149] |

| | | |
|---|---|---|
| HIV/STBBI/prevention knowledge | Prevention | ↑ Condom use (anal sex transmission risks)[139, 154] |
| | Testing | ↑ HIV testing (prevention meeting attendance, exposure to HIV information)[144, 169] |
| | Treatment | ↓ ART uptake (exposure to HIV information)[169]<br>↑ Viral suppression (exposure to HIV information)[169]<br>↓ ART adherence[158] |
| STBBI treatment history | Prevention | ↑ Condom use[154]<br>↑ PrEP uptake[165] |
| PrEP knowledge | Prevention | ↑ PrEP uptake[146] |
| History of prevention/PrEP session participation | Prevention | ↑ PrEP uptake[157, 165]<br>↓ PrEP adherence[157] |
| | Testing | ↑ History of HIV testing[144] |
| HIV status | Prevention | ↑ Condom/lubricant use (positive status) [148, 154] |
| | Testing | ↑ No testing history (negative status)[140] |
| | Treatment | ↑ Loss-to-follow-up (negative status)[40, 149]<br>↓ Visit adherence (negative status)[149] |
| Antiretroviral therapy | Treatment | ↑ ART adherence (minimal adverse effects)[162]<br>↓ Viral suppression (EFV-based regimen)[159]<br>↓ Viral suppression (higher WHO baseline clinical stage)[159] |
| Programme enrollment | Prevention | ↑ Condom/lubricant use (longer duration)[148] |
| | Treatment | ↑ Viral suppression (later initiation year)[159]<br>↓ Loss-to-follow-up (TasP enrollment)[142] |
| ***Sexual history*** | | |
| History of transactional sex | Prevention | ↓ Condom use [139]<br>↓ PrEP uptake[156] |
| | Testing | ↓ History of prenatal HIV testing (sex work during pregnancy) [163] |
| | Treatment | ↓ ART uptake[169]<br>↓ Viral suppression[169]<br>↓ Visit adherence[149]<br>↑ Loss-to-follow-up [149] |

| | | |
|---|---|---|
| History of condomless sex | Testing | ↑ HIV testing[169]<br>↑ No history of testing[140] |
| History of forced sex | Testing | ↑ History of HIV testing[169] |
| History of insertive anal sex | Prevention | ↑ PrEP uptake (increased anal sex acts in past month)[146]<br>↓ Visit adherence (insertive anal sex in past year)[149]<br>↑ Loss-to-follow-up (insertive anal sex acts in past year)[149] |
| ***Personal feelings*** | | |
| Anticipated/internalized stigma | Testing | ↓ History of HIV self-testing (fear of confidentiality breaches)[168] |
| | Treatment | ↑ ART adherence (stigma as motivator)[166]<br>↓ HIV service access[166] |
| Stigma-induced depression | Treatment | ↓ ART adherence[166] |
| Fear/anxiety/mistrust of healthcare services | Prevention | ↓ Condom/lubricant use[154] |
| | Treatment | ↑ Loss-to-follow-up (no fear)[149]<br>↓ Visit adherence (no fear)[149] |
| Health motivation | Treatment | ↑ ART adherence[161]<br>↓ ART adherence (low motivation)[161]<br>↑ HIV service access[12] |
| ***Personal circumstances*** | | |
| Financial difficulty | Treatment | ↓ ART adherence/appointment-keeping[152, 162] |
| Schedule conflicts | Treatment | ↓ ART adherence[161] |
| Transport fare | Treatment | ↓ ART adherence[161] |
| Access to daily internet use | Prevention | ↑ Condom/lubricant use[148] |
| No access to cell phone | Treatment | ↑ Loss-to-follow-up[149]<br>↓ Visit adherence[149] |

#### *4.1.2.2. Network level*

Network-level determinants associated with HIV service outcomes across the care cascade are outlined in Table 5. Initial extraction of network-level determinants on a per-study basis and according to key population group(s) and geopolitical zone(s) are provided as supplementary material (Appendix D, Table S2). Social characteristics were the most identified determinants at this level of the modified social ecological model. Disclosure of MSM status to family and partners was positively associated with HIV testing[144, 157, 169] and ART uptake (or TasP),[142] with a similar positive association observed for HIV status disclosure and ART adherence.[161] Partner disclosure of HIV status was positively associated with ART appointment keeping,[152] while partner non-disclosure was positively associated with PrEP uptake.[160]

Some partner sociodemographic factors were explored, identifying partners having formal education and the same socioeconomic status as positively associated with HIV testing, ART uptake, and viral suppression.[144] Sexual dynamics between partners, including difficulty negotiating condom use, partner not testing for HIV, and sero-discordance, were all described as facilitators of PrEP uptake.[160] Higher daily client load and non-gatekeeper control (assumed to include brothel managers, though "gatekeeper" was undefined) were also positively associated with PrEP uptake.[165]

Some discordant patterns were also observed at the network-level. While higher social support from family, partner, or peers was almost entirely positively associated with service outcomes across prevention,[157] testing,[144] and treatment domains,[144, 161] trusting the majority of their MSM friends was negatively associated with maintaining visit adherence and positively associated with loss-to-follow-up (MSM and transgender people in the North-Central and South-

West zones).[149] Similarly, larger network size/density was a facilitator of PrEP uptake,[157] history of HIV testing, ART uptake (when paired with social support), and viral suppression.[144]

**Table 5. Network-level determinants associated with HIV service outcomes among key populations in Nigeria.**

| Determinant | Care continuum stage | Finding (↑=positively-associated, ↓=negatively-associated) |
|---|---|---|
| ***Sociodemographic factors*** | | |
| Formal education (partner) | Testing | ↑ HIV testing[144] |
| | Treatment | ↑ ART uptake[144] |
| Socioeconomic status (partner) | Treatment | ↑ ART uptake (the same SES)[144]<br>↑ Viral suppression (the same SES)[144] |
| ***Social characteristics*** | | |
| Disclosure of MSM/HIV status to family/partners (self) | Testing | ↑ History of HIV testing (MSM disclosure)[144, 157, 169] |
| | Treatment | ↑ ART uptake/TasP enrollment (MSM disclosure)[142]<br>↑ ART adherence (HIV status disclosure)[161] |
| Disclosure of HIV status (partner) | Prevention | ↑ PrEP uptake (partner non-disclosure)[160] |
| | Treatment | ↑ ART appointment-keeping (knowledge of partner's status)[152] |
| Higher social support from family/partner/peers | Prevention | ↑ PrEP uptake[157] |
| | Testing | ↑ History of HIV testing[144] |
| | Treatment | ↑ ART uptake[144]<br>↑ ART adherence[161]<br>↑ Viral suppression[144]<br>↑ Visit adherence (MSM and heterosexual friends)[149]<br>↓ Visit adherence (trust the majority of MSM friends)[149]<br>↑ Loss-to-follow-up (trust the majority of MSM friends)[149] |
| Higher network density/size | Prevention | ↑ PrEP uptake (network density ≥ 50%)[157] |
| | Testing | ↑ History of HIV testing (network size >10)[144] |
| | Treatment | ↓ ART uptake (network size 11–20)[144]<br>↑ ART uptake (larger network size and social support)[144] |

| | | |
|---|---|---|
| | | ↑ Viral suppression (larger network size and social support)[144] |
| ***Sexual dynamics*** | | |
| Partner dynamics | Prevention | ↑ PrEP uptake (inability to negotiate condom use, partner refuses HIV testing, sero-discordant relationship)[160] |
| Transactional sex | Prevention | ↑ PrEP uptake (higher daily client load, non-gatekeeper control)[165] |

#### *4.1.2.3. Community level*

Many community-level determinants of service outcomes were identified across the HIV continuum of care, as presented in Table 6. Initial extraction of community-level determinants on a per-study basis and according to key population group(s) and geopolitical zone(s) are provided as supplementary material (Appendix D Table S3). These determinants were classified as location-based, experience-based, or programme delivery-based.

Geographical distance was found to be negatively associated with prevention service access[13] and ART adherence[158, 161, 162] in most cases, although a facilitator of HIV service access in one study through supporting confidentiality measures.[151] Geographical proximity to a service was described as a facilitator of ART retention,[158] while uneven geographic availability of HIV services was described as a barrier to service access.[151] Inconsistent trends were also observed according to study site. Relative to studies positioned in Abuja (or the Federal Capital Territory; North-Central zone), Lagos (South-West zone) as a study site was positively associated with condom and lubricant use as well as maintaining visit adherence (MSM and transgender people)[148, 149, 154] but negatively associated with an HIV testing history (MSM).[140] In turn, another study observed Abuja as a study site to be a facilitator of ART uptake relative to Lagos (MSM).[144]

Disclosure of MSM status to providers was frequently discussed. Disclosure of MSM status to healthcare providers was positively associated with consistent condom use,[154] HIV testing,[144] ART uptake (or TasP),[40, 142] and viral suppression,[40, 144] while non-disclosure of MSM status was negatively associated with ART retention[158] and maintaining visit adherence[149] and positively associated with loss-to-follow-up.[149] Stigma and discrimination from providers were also commonly described as a barrier to ART adherence,[161, 162] ART retention,[158] and HIV

service access.[58, 151] Feeling safe and comfortable with providers was positively associated with HIV testing[49] and ART access in some studies,[162] while fear associated with provider learning MSM status was negatively associated with HIV testing.[49] Similarly, having confidentiality maintained was a facilitator to prevention service access[13] and ART retention,[158, 162] while confidentiality concerns were barriers to prevention service access,[13] HIV testing,[49] and HIV service access.[151]

Programme delivery factors were the most frequently identified determinants at the community level. For testing uptake, outreach paired with counselling, testing, and MPPI delivery,[141] a phone hotline for additional information,[145] and non-health services[49] offered at testing facilities were all described as facilitators. For treatment uptake, offering adherence counselling, tracking and follow-up, community-led or drug refill by proxy, peer support, comprehensive care, and wrap-around services were all described as facilitators.[158, 161] Having a shared treatment delivery model among all key population groups was described as a barrier to HIV treatment,[158] as were a lack of comprehensive services, key population-friendly facilities, key population-specific information, and the unavailability of providers.[12] Programme staff and environment also emerged as important determinants, with poor staff attitudes and hasty physician review, non-key population member healthcare workers, misgendering of patients, and a lack of specialist skills negatively associated with prevention[13, 147] and treatment outcomes,[158, 161] as well as general HIV service access.[58, 151] Meanwhile, having key population member healthcare workers, encouraging staff, and a conducive clinic environment (e.g., feeling safe, comfortable with provider, incorporate peer support and referral, offering comprehensive and non-health HIV care services) was positively associated with HIV testing[49] and ART retention

and adherence.[158, 161] Finally, out-of-pocket expenses was negatively associated with prevention access[13, 147] and ART retention.[151]

**Table 6. Community-level determinants associated with HIV service outcomes among key populations in Nigeria.**

| Determinant | Care continuum stage | Finding (↑=positively-associated, ↓=negatively-associated) |
|---|---|---|
| ***Location-based factors*** | | |
| Geographical access | Prevention | ↑ Condom/lubricant use (Lagos)[148, 154]<br>↓ Prevention service access (distance at peer-led facilities, PWID)[13] |
| | Testing | ↓ History of HIV testing (Ibadan/Lagos)[140]<br>↓ Prenatal HIV testing (South-South zone)[163] |
| | Treatment | ↑ ART uptake (Abuja)[144]<br>↓ ART adherence (distance to facility)[158, 161, 162]<br>↑ ART retention (proximity to service)[158]<br>↑ Visit adherence (Lagos)[149]<br>↑ ART attrition (rural and urban vs. semi-urban)[153] |
| | General HIV services | ↑ HIV service access (greater distance supporting confidentiality)[151]<br>↓ HIV service access (uneven geographic availability)[151] |
| Location typology | Testing | ↓ Prenatal HIV testing (non-brothel-based)[163] |
| ***Group membership-based factors*** | | |
| Religion | Prevention | ↑ PrEP use (Christian religion)[165] |
| | Prevention | ↓ PrEP uptake (Muslim/non-Chistian religion)[163] |
| | Treatment | ↓ ART uptake/TasP engagement (Muslim/non-Chistian religion)[142, 144]<br>↑ Viral suppression (Muslim/non-Chistian religion)[144] |
| ***Healthcare experiences*** | | |

| | | |
|---|---|---|
| Disclosure to providers | Prevention | ↑ Consistent condom use (MSM status was disclosed)[154] |
| | Testing | ↑ History of HIV testing (MSM status disclosed)[144] |
| | Treatment | ↑ ART uptake/TasP enrollment (MSM status disclosed)[40, 142]<br>↑ Viral suppression (MSM status disclosed)[40, 144]<br>↓ ART retention (non-disclosure of HIV status)[158]<br>↓ Visit adherence (non-disclosure of MSM status)[149]<br>↑ Loss-to-follow-up (non-disclosure of MSM status)[149] |
| Provider stigma/discrimination | Treatment | ↓ ART adherence (general stigma)[161, 162]<br>↓ ART retention (intrafacility stigma, MSM in particular)[158] |
| | General HIV services | ↓ HIV service access (misgendering, refusal of service, anticipated stigma, discriminatory responses)[58, 151] |
| Safety and comfort | Testing | ↑ History of HIV testing (peer referral, feeling safe/belonging, comfort with provider at community facility)[49]<br>↓ History of HIV testing (fear of provider learning MSM status, fear of stigma reducing MSM disclosure)[49] |
| | Treatment | ↑ ART access (comfort discussing health concerns at OSS)[162] |
| Confidentiality concerns | Prevention | ↑ Prevention service access (confidentiality maintained at peer-led facilities)[13]<br>↓ Prevention service access (concerns at public facilities, particularly among PWID)[13] |
| | Testing | ↓ History of HIV testing (concern at public facilities)[49] |
| | Treatment | ↑ ART retention (confidentiality maintained)[158, 162] |

| | | |
|---|---|---|
| | | ↓ HIV service access (concerns at general facilities)[151] |
| ***Programme delivery factors*** | | |
| Programme delivery and ancillary services | Testing | ↑ History of HIV self-testing (phone hotline for information, counselling, treatment linkage)[145]<br>↑ History of HIV testing (mobile outreach with dedicated counselling and testing team/MPPI delivery)[141]<br>↑ History of HIV testing (non-health HIV care services being offered at facility)[49]<br>↓ HIV testing (insufficient psychosocial services at facility)[49] |
| | Treatment | ↑ ART adherence (adherence counselling, tracking/follow-up, community-led refill)[155, 158, 161]<br>↑ ART retention (peer support, comprehensive care, incentives, wrap-around services, proxy refill)[158]<br>↓ ART retention (shared key population model risking disclosure; no smoking area)[158] |
| | General HIV services | ↓ HIV service access (lack of free/comprehensive services, key population-friendly facilities, key population-specific information, and provider availability)[12] |
| Programme logistics | Prevention | ↓ Prevention access (operating hours, wait times, patient volume at public facilities)[13, 147] |
| | Treatment | ↑ ART retention (short wait times, low patient load, appointment reminders)[158]<br>↓ HIV service access (overcrowding, long wait times)[151] |
| Programme staff/environment | Prevention | ↓ Prevention access (poor staff attitudes, hasty physician review at public facilities)[13, 147] |
| | Testing | ↑ History of HIV testing (facility has MSM staff)[49] |

| | | |
|---|---|---|
| | Treatment | ↑ ART retention (key population-member HCWs, encouraging staff, conducive environment at OSS)[158, 162]<br>↓ ART retention/adherence (non-key population HCWs, poor provider attitude)[158, 161] |
| | General HIV services | ↓ HIV service access (misgendering, hostile staff, lack of specialist skills)[58, 151]<br>↓ HIV service access (limited key population-friendly clinics)[151] |
| Service accessibility/affordability | Prevention | ↓ Prevention access (out-of-pocket costs, service fees)[13, 147] |
| | Testing | ↑ History of prenatal HIV testing (antenatal care access)[163] |
| | Treatment | ↓ ART retention (service fees)[151] |

#### *4.1.2.4. Policy level*

Few policy-level determinants explicitly associated with HIV service outcomes were described in retained records, as illustrated in Table 7. Criminalization was described most frequently in the peer-reviewed literature, referring to the 2014 Same-Sex Marriage (Prohibition) Act.[40, 58, 151] One study reported decreased HIV testing uptake and increased loss-to-follow-up post-law compared to the pre-law period.[40] In more recent studies, criminalization was described as a barrier to HIV service access[151] and gender identity disclosure to healthcare providers among transgender people.[58]

Programme delivery, particularly rollout and funding, were also mentioned as barriers to HIV prevention services. The first pilot programmes for needle and syringe services were implemented in 2019-2020, but were limited to PWID and to three states, encompassing North-East, South-East, and South-West zones,[137] and scale-up to the South-South zone in 2022.[170] However, in the wake of global funding cessation during 2025, these services were cut back to four states, whose locations were not identified.[138] These reductions in global spending also coincided with a 55% reduction in male condom distribution in the country between December 2024 and March 2025, and the closure of at least five prevention clinics for key populations.[138]

**Table 7. Policy-level determinants associated with HIV service outcomes among key populations in Nigeria.**

| Determinant | Care continuum stage | Finding (↑=positively-associated, ↓=negatively-associated) |
|---|---|---|
| ***Legal factors*** | | |
| Criminalization of same-sex relationships | Testing | ↓ History of HIV testing (post-law vs. pre-law)[40] |
| | Treatment | ↑ Loss-to-follow-up (post-law)[40] |
| | General HIV service access | ↓ HIV service access[151]<br>↓ Gender identity disclosure to providers (fear of legal repercussion)[58] |
| ***Programme delivery factors*** | | |
| Programme coverage | Prevention | ↓ NSP pilot in 2019 limited to PWID only[137]<br>↓ NSP pilot in 2019 limited to three geopolitical zones, expanded to four in 2022[137] |
| Global funding losses in 2025 | Prevention | ↓ Reduced male condom distribution[138]<br>↓ NSP services limited to four sites[138]<br>↓ Closure of key population prevention clinics[138] |

## 4.2. Molecular Epidemiology – Objective 2

### 4.2.1. Sequence dataset

Of the IBBSS participants identified as HIV-seropositive with a linked questionnaire and viral load data (n=2,279), 719 (31.5%) samples were identified as HIV viremic (viral load ≥1,000 copies/mL). Although an overlapping portion of the HIV *pol* gene was amplified, protease gene sequences were retained for subsequent phylogenetic analyses to maximize the sample size, yielding 547 (76.1%) recoverable sequences from 719 viremic specimens. The final sequence dataset comprised 185 (33.8%) FSW, 176 (32.2%) MSM, 135 (24.7%) transgender people, and 51 (9.3%) PWID. Sociodemographic information for the full IBBSS dataset, HIV sero-positive, viremic, and sequenced subgroups are presented as supplementary material (Appendix E, Table S4). The workflow for sequence extraction from DBS stratified by key population group is illustrated in Figure 8.

Sociodemographic, behavioural, and virologic characteristics of key populations from which an HIV protease sequence was obtained are presented in Table 8. The majority of participants were under the age of 25 (*n*=238/547, 44%), living in the South-West geopolitical zone (*n*=137/547, 25%), had secondary or lower education (*n*=427/547, 78%), were single (*n*=442/547, 81%), and reported being employed/other (*n*=272/547, 50%). The most frequently observed location typology was residential/private (43%), followed by nightlife/sex venues (35%), and street/virtual/other (22%).

Knowledge of a place to receive HIV counselling and testing services (53%, n=289/547) was higher compared to contact by an outreach worker (33%, n=178/547), though most recent HIV test within the past year exceeded both these programme variables (67%, n=368/547). DBS specimens were evenly distributed across viral load categories, with a slightly higher percentage

≥50,000 copies/mL (39%). Protease sequences were mainly classified as HIV subtypes CRF02_AG and G (68% and 26%, respectively).

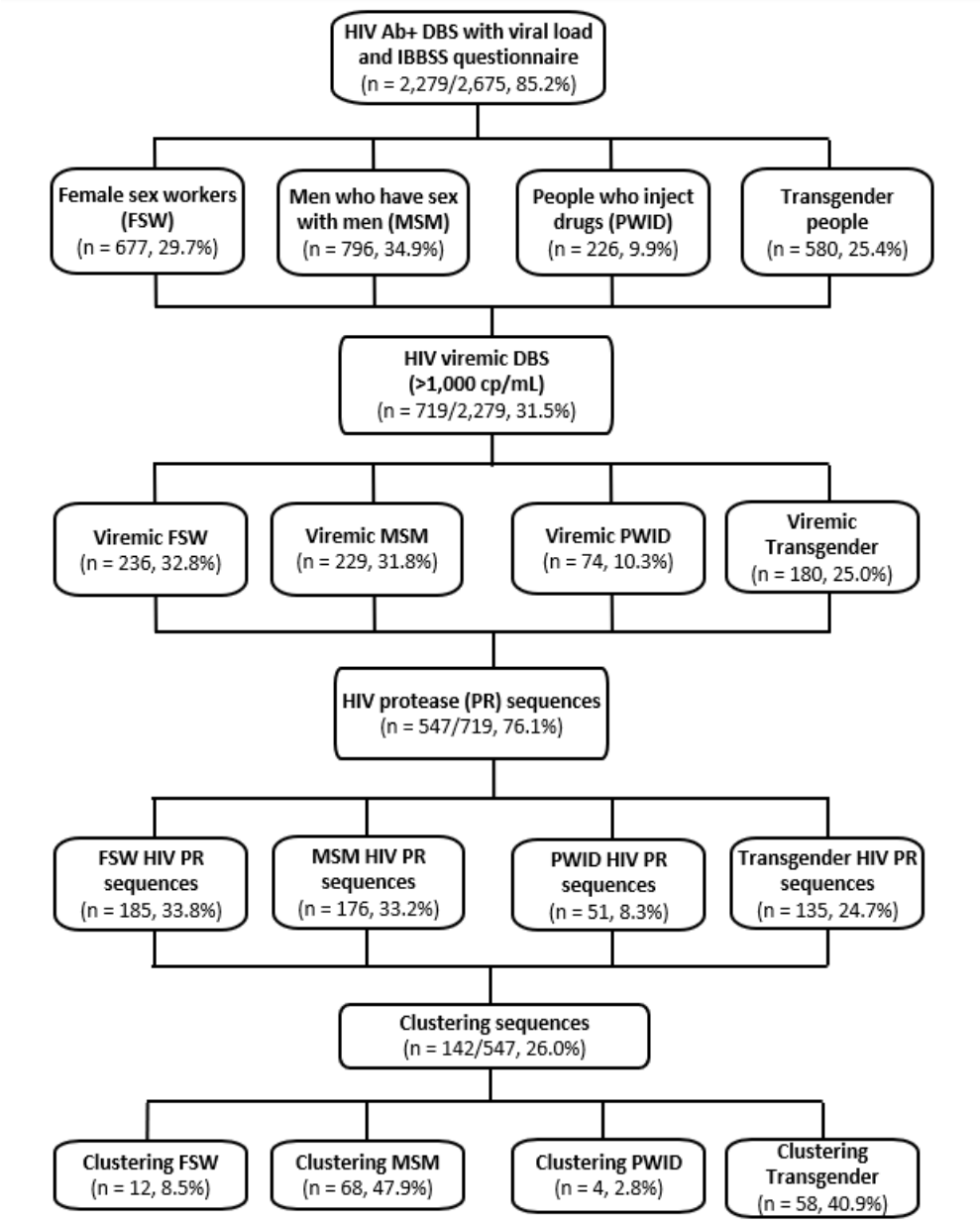


**Figure 8. HIV protease sequence recovery and phylogenetic cluster workflow by key population; Nigerian IBBSS (2020).**

**Table 8. Sociodemographic, behavioural, and virologic characteristics of key populations living with HIV; Nigerian IBBSS (2020).**

| | | **HIV protease sequences (N=547)** |
|---|---|---|
| *Gender identity* | Man | 333 (60.9) |
| | Woman | 214 (39.1) |
| *Age group* | <25 | 238 (43.5) |
| | 25-29 | 162 (29.6) |
| | 30-34 | 72 (13.2) |
| | 35+ | 75 (13.7) |
| *Key population* | FSW | 185 (33.8) |
| | MSM | 176 (32.2) |
| | PWID | 51 (9.3) |
| | Transgender people | 135 (24.7) |
| *Geopolitical zone* | North-Central | 75 (13.7) |
| | North-East | 78 (14.3) |
| | North-West | 79 (14.4) |
| | South-East | 69 (12.6) |
| | South-South | 109 (19.9) |
| | South-West | 137 (25.1) |
| *Highest level of education obtained* | Secondary or less | 427 (78.1) |
| | Tertiary | 120 (21.9) |
| *Marital status* | Non-single | 105 (19.2) |
| | Single | 442 (80.8) |
| *Employment status* | Employed /Other | 272 (49.7) |
| | Unemployed | 203 (37.1) |
| | Student/Retired/DK/NR | 72 (13.2) |
| *Location typology* | Nightlife/sex venue | 197 (35.3) |
| | Residential/private | 228 (42.5) |

| | | |
|---|---|---|
| | Street/virtual/other | 122 (22.2) |
| *Knows of a place to receive HIV counselling and testing* | Yes | 289 (52.8) |
| | No | 234 (42.8) |
| | DK/NR | 24 (4.4) |
| *Contacted by an outreach worker to provide HIV/AIDS services in past year* | Yes | 178 (32.5) |
| | No | 344 (62.9) |
| | DK/NR | 25 (4.6) |
| *Received most recent HIV test within the past year* | Yes | 368 (67.3) |
| | No | 93 (17.0) |
| | DK/NR | 86 (15.7) |
| *HIV viral load (copies/mL)* | <10,000 | 166 (30.4) |
| | 10,000–49,999 | 168 (30.7) |
| | ≥50,000 | 213 (38.9) |
| *HIV subtype* | CRF02_AG | 369 (67.5) |
| | G | 141 (25.8) |
| | CPX | 20 (3.7) |
| | A | 17 (3.1) |

All results presented as *n* (%). "DK/NR" indicates "Don't Know/No Response" and includes unknown and missing responses. Non-single includes currently married and divorced/separated/widowed.

### 4.2.2. Phylogenetic clustering

Of 547 HIV *protease* sequences, 142 (25.9%) sequences formed 47 phylogenetic clusters ranging in size from 2-8 sequences, which are presented in Figures 9-12. Most phylogenetic clusters (n=30/47, 64%) contained both MSM and transgender people, with fewer clusters comprising exclusively MSM (n=4/47) or exclusively transgender people (n=6/47). The seven remaining clusters comprised exclusively FSW (n=3/47), both FSW and PWID (n=2/47), and

both PWID and MSM (n=2/47). The majority of clusters were from the South-West geopolitical zone (n=18/47, 38%), followed by the South-South (n=10/47), North-East (n=8/47), North-Central (n=5/47), South-East (n=4/47), and North-West (n=2/47) zones, as shown in Figure 9. Mixing between sequences from geopolitical zones was rare, only occurring in a single phylogenetic cluster between the South-East and South-West zones. For the remainder of cluster descriptions, this single mixed cluster will be consolidated with those from the South-East zone.

Knowledge of where to receive HIV counselling and testing services was mixed across phylogenetic clusters from geopolitical zones, as illustrated in Figure 10. Of all phylogenetic clusters, 87% (n=41/47) contained at least one participant aware of a place to receive HIV counselling and testing services. However, only 26% (n=12/47) comprised entirely participants who were aware of such a place. By geopolitical zone, between 83-100% of clusters from each zone contained at least one participant who knew where to receive HIV counselling and testing services. This included nearly all phylogenetic clusters from the South-South (n=9/10), South-East (n=4/4), North-West (n=2/2), and most from the North-Central (n=4/5), North-East (n=7/8), and South-West (n=15/18) zones.

Contact by an outreach worker for HIV/AIDS in the past year was markedly lower compared to knowledge of HIV counselling and testing services, shown in Figure 11. Among all phylogenetic clusters, just over half (60%, n=28/47) of clusters contained at least one participant who was contacted by an outreach worker in the past year, but over one-third (34%, n=16/47) of clusters contained exclusively participants who had not been contacted. The South-East zone had the highest percentage (75%, n=3/4) of clusters with exclusively participants that were not contacted, which was followed by the North-Central (60%, n=3/5), South-West (33%, n=6/18),

South-South (30%, n=3/10), and North-East (13%, n=1/8) zones. The few (n=2) clusters detected from the North-West zone did not contain any participants who had been contacted.

In contrast to contact by an outreach worker, HIV testing within the past year was observed to be high, presented in Figure 12. We found 89% (n=42/47) of all phylogenetic clusters contained at least one participant who received their most recent HIV test within the past year, of which almost one-half (45%, n=21/47) of clusters contained exclusively participants who had received their most recent HIV test within the past year. Such clusters were observed in highest percentage in the South-South zone (80%, n=8/10), followed by the North-East (63%, n=5/8), North-West (50%, n=1/2), North-Central (40%, n=2/5), South-West (28%, n=5/18), and lowest in the South-East (25%, n=1/4). However, it should be noted that 18% and 15% of clustering and non-clustering participants did not respond to this question.

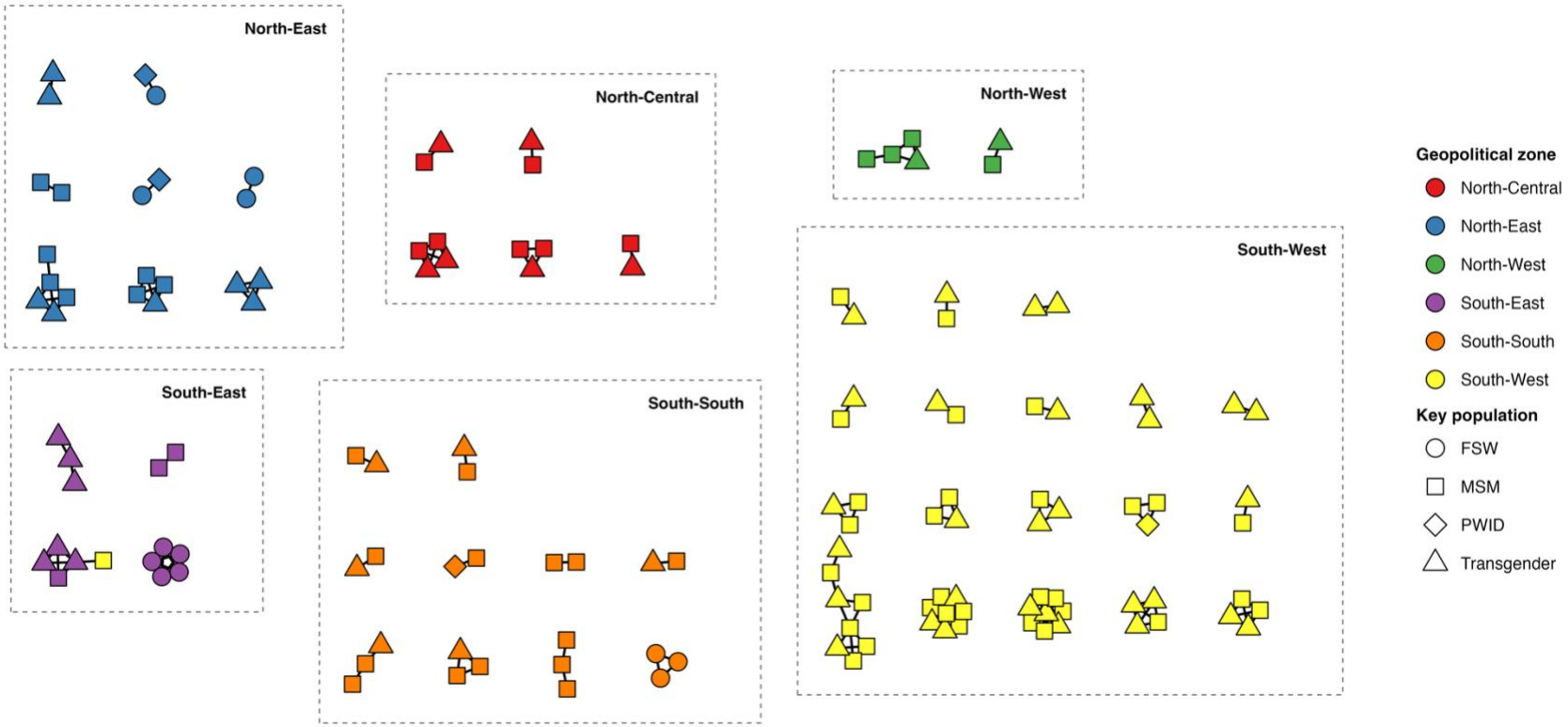


**Figure 9. Phylogenetic clustering of HIV protease sequences derived from key populations in Nigeria, by geopolitical zone; Nigerian IBBSS (2020).**

Key populations stand for: Female sex workers (FSW), men who have sex with men (MSM) and people who inject drugs (PWID).

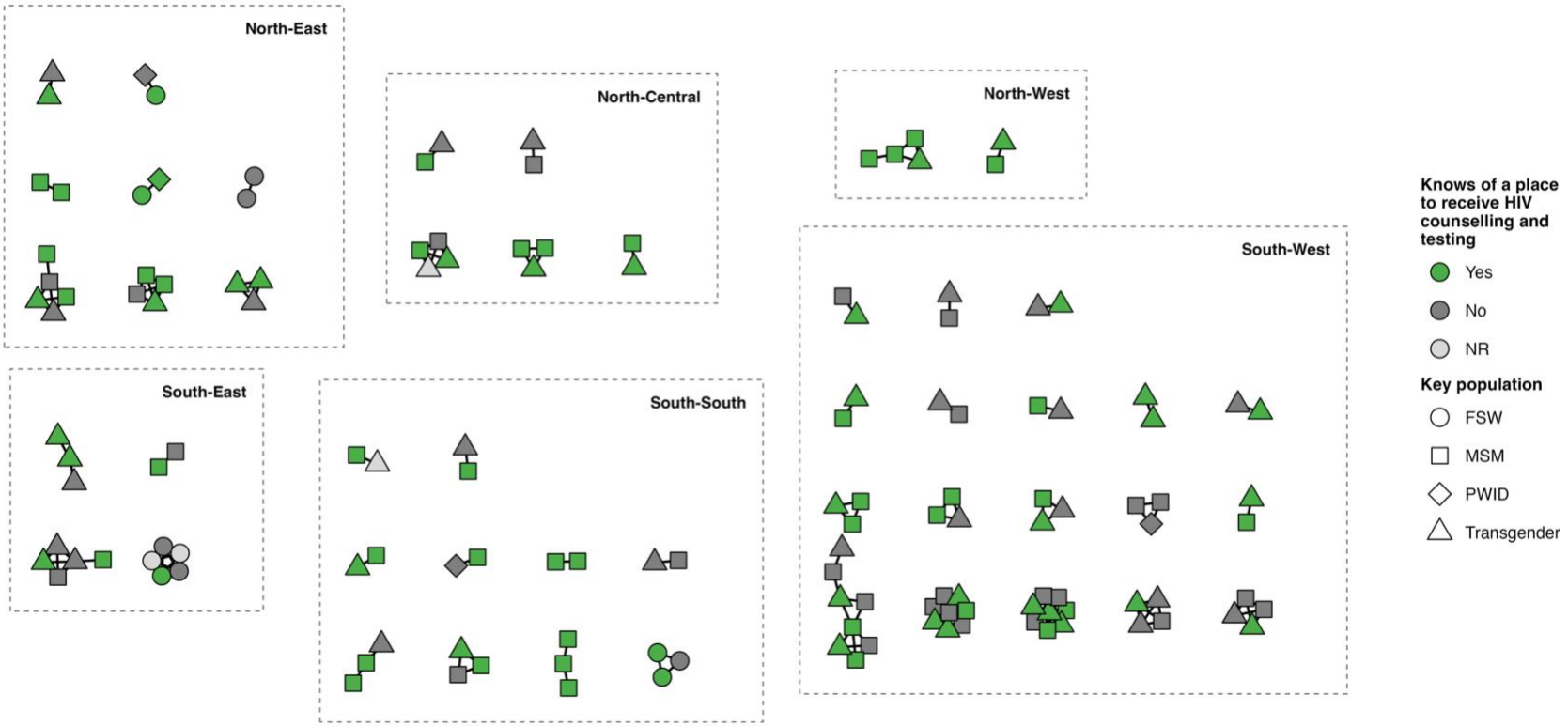


**Figure 10. Phylogenetic clustering of HIV protease sequences derived from key populations Nigeria, by knowledge of a place to receive HIV counselling and testing services; Nigerian IBBSS (2020).**

Key populations stand for: Female sex workers (FSW), men who have sex with men (MSM) and people who inject drugs (PWID).

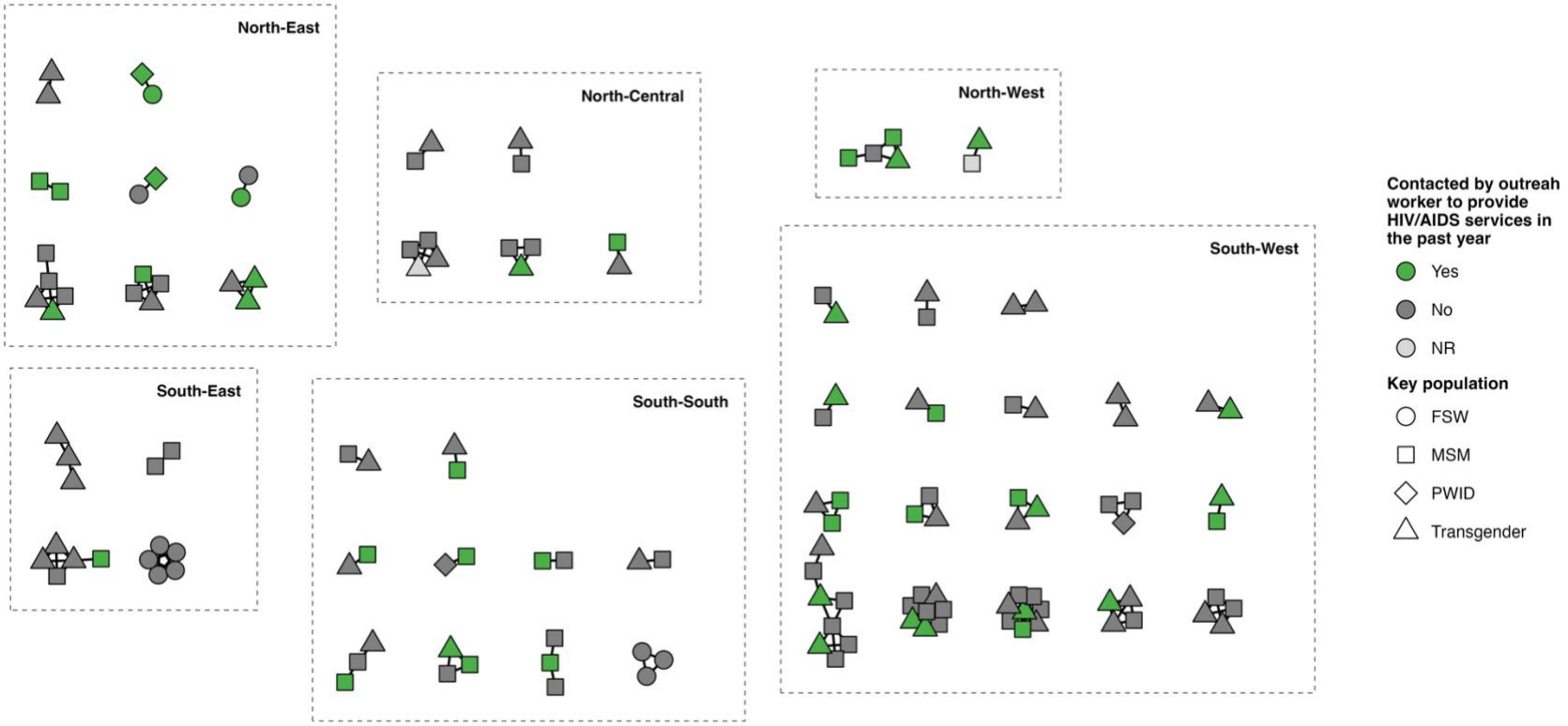


**Figure 11. Phylogenetic clustering of HIV protease sequences derived from key populations in Nigeria, by contact with an outreach worker for HIV/AIDS services in the past year; Nigerian IBBSS (2020).**

Key populations stand for: Female sex workers (FSW), men who have sex with men (MSM) and people who inject drugs (PWID).

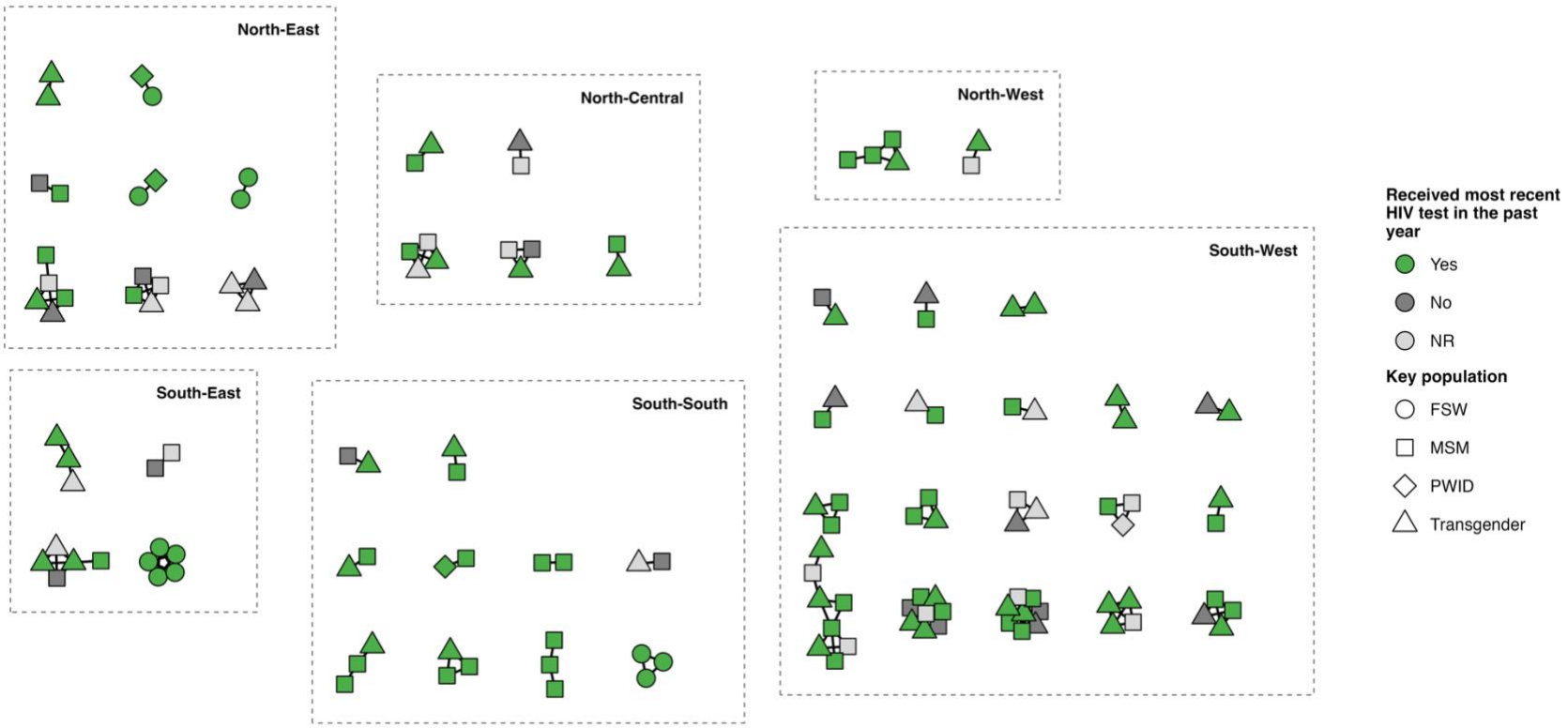


**Figure 12. Phylogenetic clustering of HIV protease sequences derived from key populations in Nigeria, by receipt of an HIV test in the past year; Nigerian IBBSS (2020).**

Key populations stand for: Female sex workers (FSW), men who have sex with men (MSM) and people who inject drugs (PWID).

#### *4.2.2.1. Statistical associations*

Several predictors were found to be significantly associated with phylogenetic cluster membership through bivariate chi-square tests (p-value<0.05), as shown in Table 9. This included gender identity, age group, geopolitical zone, highest educational level obtained, marital status, employment status, and HIV viral load. Clustering participants mainly identified as men (*n*=72/142, 51%), were under the age of 25 years (*n*=79/142, 56%), resided in the south-west (*n*=63/142, 44%), had secondary education or below (*n*=95/142, 67%), and were single (*n*=132/142, 93%), respectively. Neither location typology nor any programme coverage indicators (availability, coverage, or utilization) reached statistical significance by chi-square.

**Table 9. Sociodemographic, behavioural, and virologic characteristics of key populations living with HIV stratified by phylogenetic cluster membership; Nigerian IBBSS (2020).**

| | | Non-clustering [a] | Clustering [a] | *p*-value [b] |
|---|---|---|---|---|
| **N (Col %)** | | **405 (100.0)** | **142 (100.0)** | |
| *Gender identity* | Male | 261 (64.4) | 72 (50.7) | 0.004 ** |
| | Female | 144 (35.6) | 70 (49.3) | |
| *Age group (years)* | <25 | 159 (39.3) | 79 (55.6) | 0.004 ** |
| | 25-29 | 127 (31.4) | 35 (24.7) | |
| | 30-34 | 55 (13.6) | 17 (12.0) | |
| | 35+ | 64 (15.8) | 11 (7.8) | |
| *Key population* | FSW | 173 (42.7) | 12 (8.5) | -- |
| | MSM | 108 (26.7) | 68 (47.9) | |
| | PWID | 47 (11.6) | 4 (2.8) | |
| | TG | 77 (19.0) | 58 (40.9) | |
| *Geopolitical zone* | North-Central | 62 (15.3) | 13 (9.2) | < 0.001 *** |
| | North-East | 56 (13.8) | 22 (15.5) | |
| | North-West | 73 (18.0) | 6 (4.2) | |
| | South-East | 55 (13.6) | 14 (9.9) | |
| | South-South | 85 (21.0) | 24 (16.9) | |
| | South-West | 74 (18.3) | 63 (44.4) | |
| *Highest level of education obtained* | Secondary or less | 332 (82.0) | 95 (66.9) | < 0.001 *** |
| | Tertiary | 73 (18.0) | 47 (33.1) | |
| *Marital status* | Non-single [c] | 95 (23.5) | 10 (7.0) | < 0.001 *** |
| | Single | 310 (76.5) | 132 (93.0) | |
| *Employment status [d]* | Employed/Other | 200 (49.4) | 72 (50.7) | 0.001 ** |
| | Unemployed | 163 (40.3) | 40 (28.2) | |
| | Student/Retired/DK/ NR | 42 (10.4) | 30 (21.1) | |
| *Location typology* | Nightlife/Sex venue | 143 (35.3) | 54 (38.0) | 0.800 |

| | | | | |
|---|---|---|---|---|
| | Residential/private | 172 (42.5) | 56 (39.4) | |
| | Street/virtual/other | 90 (22.2) | 32 (22.5) | |
| *Knows of a place to receive HIV counselling and testing* [d] | Yes | 207 (51.1) | 82 (57.8) | 0.252 |
| | No | 178 (44.0) | 56 (39.4) | |
| | DK/NR | 20 (4.9) | 4 (2.8) | |
| *Contacted by an outreach worker to provide HIV/AIDS services in past year* [d] | Yes | 135 (33.3) | 43 (30.3) | 0.323 |
| | No | 247 (61.0) | 97 (68.3) | |
| | DK/NR | 23 (5.7) | 2 (1.4) | |
| *Received most recent HIV test within the past year* [d] | Yes | 271 (66.9) | 97 (68.3) | 0.337 |
| | No | 73 (18.0) | 20 (14.1) | |
| | DK/NR | 61 (15.1) | 25 (17.6) | |
| *HIV subtype* | CRF02_AG | 254 (62.7) | 115 (81.0) | -- |
| | G | 126 (31.1) | 15 (10.6) | |
| | CPX | 16 (4.0) | 4 (2.8) | |
| | A | 9 (2.2) | 8 (5.6) | |

[a] Phylogenetic cluster membership defined as a pairwise genetic distance < 0.02 substitutions per site and >50% bootstrap support.

[b] P-values derived from Pearson Chi-square tests with statistical significance denoted as: $^{*}$ $p < 0.05$, $^{**}$ $p < 0.01$, $^{***}$ $p < 0.001$.

[c] Non-single includes currently married and divorced/separated/widowed.

[d] "DK/NR" indicates "Don't Know/No Response", which includes missing responses and was not included in the Chi-square calculation when un-consolidated with another response.

Unadjusted Poisson regression indicated age group, key population, geopolitical zone, education level, and marital and employment status were significant predictors of clustering, shown in Table 10. After adjustment, only key population group and geopolitical zone remained significant predictors, and their associations with phylogenetic cluster membership were attenuated. Compared to FSW, MSM (aPR: 5.38 [95% CI: 2.87, 10.07]) and transgender people (aPR: 5.52 [95% CI: 2.96, 10.28]) had over five times the prevalence of phylogenetic clustering. Compared to the North-Central zone, participants in North-East (aPR: 1.91 [95% CI: 1.07, 3.41]) and South-West (aPR: 1.88 [95% CI: 1.13, 3.12] zones had significantly higher prevalence of phylogenetic clustering. No programme coverage indicators, nor any location typologies reached statistical significance in unadjusted or fully adjusted models.

**Table 10. Factors associated with phylogenetic cluster membership among key populations living with HIV; Nigerian IBBSS (2020).**

| | Unadjusted PR [95% CI] | Adjusted PR (aPR) [95% CI] |
|---|---|---|
| *Age group* | | |
| <25 | Ref | Ref |
| 25-29 | **0.65 * [0.46, 0.92]** | 0.87 [0.62, 1.22] |
| 30-34 | 0.71 [0.45, 1.12] | 1.25 [0.82, 1.91] |
| 35+ | **0.44 ** [0.25, 0.79]** | 0.80 [0.48, 1.34] |
| *Key population* | | |
| FSW | Ref | Ref |
| MSM | **5.96 *** [3.34, 10.62]** | **5.38 *** [2.87, 10.07]** |
| PWID | 1.21 [0.41, 3.59] | 1.44 [0.49, 4.22] |
| Transgender | **6.62 *** [3.71, 11.84]** | **5.52 *** [2.96, 10.28]** |
| *Geopolitical zone* | | |
| North-Central | Ref | Ref |
| North-East | 1.63 [0.89, 2.99] | **1.91 * [1.07, 3.41]** |
| North-West | 0.44 [0.18, 1.09] | 0.63 [0.26, 1.53] |
| South-East | 1.17 [0.59, 2.31] | 1.06 [0.55, 2.02] |
| South-South | 1.27 [0.69, 2.33] | 1.10 [0.62, 1.96] |
| South-West | **2.65 *** [1.57, 4.49]** | **1.88 * [1.13, 3.12]** |
| *Highest level of education obtained* | | |
| Tertiary | Ref | Ref |
| Less than tertiary | **0.57 *** [0.43, 0.76]** | 0.81 [0.61, 1.08] |
| *Marital status* | | |
| Non-single | Ref | Ref |
| Single | 3.14 [1.71, 5.75] | 1.60 [0.96, 2.67] |
| *Employment status* | | |
| Employed/other | Ref | Ref |
| Student/retired/DK/NR | **1.57 ** [1.12, 2.21]** | 1.09 [0.77, 1.54] |

| | | |
|---|---|---|
| Unemployed | 0.74 [0.53, 1.05] | 1.04 [0.74, 1.48] |
| *Location typology* | | |
| Nightlife/Sex venue | Ref | Ref |
| Residential/Private | 0.90 [0.65, 1.24] | 0.74 [0.55, 1.00] |
| Street/virtual/other | 0.96 [0.66, 1.39] | 0.79 [0.55, 1.15] |
| *Knows of a place to receive counselling on HIV/AIDS* | | |
| Yes | Ref | Ref |
| No | 0.84 [0.63, 1.13] | 1.21 [0.88, 1.67] |
| DK/NR | 0.59 [0.24, 1.46] | 2.37 [0.88, 6.35] |
| *Contacted by a peer worker to provide HIV/AIDS services in past year* | | |
| Yes | Ref | Ref |
| No | 1.17 [0.86, 1.59] | 1.08 [0.79, 1.47] |
| DK/NR | 0.33 [0.09, 1.28] | 0.53 [0.12, 2.40] |
| *Received most recent HIV test within the past year* | | |
| Yes | Ref | Ref |
| No | 0.82 [0.53, 1.25] | 0.80 [0.55, 1.17] |
| DK/NR | 1.10 [0.76, 1.60] | 0.99 [0.71, 1.40] |

$^{*}$ $p < 0.05$, $^{**}$ $p < 0.01$, $^{***}$ $p < 0.001$. "DK/NR" indicates "Don't Know/No Response" and includes missing responses. Non-single includes currently married and divorced/separated/widowed. All $GVIF^{(1/(2*df))} < 1.20$.

### 4.2.3. Phylodynamic modelling

While models were constructed for the two dominant HIV subtypes from the sequence dataset, results from subtype CRF02_AG are presented for the effective population size estimates, as these model parameters had sufficient support. Subtype G models are provided as supplementary

material for these results (Appendix F, Figures S4-S5). However, results from both subtypes are presented for the ancestral migration event results, as subtype CRF02_AG model parameters did not have strong support. Supporting ESS values for all models are included in Appendix F (Figures S2, S3, S6, S7).

#### *4.2.3.1. Effective population size estimates*

Bayesian skyline plot analyses of key population groups and geopolitical zones among people living with HIV in Nigeria for the period of 2000 to 2020 suggests that groups experienced slightly different phases of HIV exponential growth (Figure 13, Panel A). This is illustrated by steeper slopes in epidemic trajectories. For FSW, this growth phase occurred the earliest, around 2000, and its effective population size reached the highest magnitude before plateauing in 2007. For MSM, an initial growth phase occurred in 2004 before plateauing around 2007, and a second, smaller growth phase occurred around 2014 before plateauing around 2016. Transgender people showed very similar trends to the MSM group. For PWID, the latest growth phase was observed, beginning in 2008 and plateauing shortly after 2010.

In contrast to key population models, a Bayesian skyline plot analysis among key populations living with HIV by Nigerian geopolitical zone suggest that periods of HIV exponential growth initiated later and were similar across zones (Figure 13, Panel B). The North-Central and South-South geopolitical zones followed similar time trends for early effective population size growth, both initiating around 2004. However, the South-South zone's effective population size initiated at a much higher magnitude, and rather than plateauing completely, continues to rise gradually until the time samples were collected. The North-Central zone exhibited the steepest slope in HIV epidemic trajectory until reaching a plateau around 2012. The North-East and North-West zones similarly both displayed periods of growth in effective

population size around 2007, albeit at different magnitudes, but while the North-East zone appeared to plateau around 2010, the North-West continued to rise until the time of sampling, reaching the highest magnitude in effective population size of any other geopolitical zone. Finally, the South-West and South-East effective population sizes initiated at similar times and magnitudes around 2008, with similar slopes in epidemic trajectories that rise gradually to peak around 2016.

Overlaying the key population Bayesian skyline plots with the estimated Nigerian population living with HIV suggests that phases of epidemic growth among key populations broadly coincide with an increasing pool of people living with HIV over the same period (Figure 14), and a similar pattern of overlap was observed when HIV spending expenditure data targeting "most-at-risk populations" (all sources: public, private, and donor) were overlaid on geopolitical zone Bayesian skyline plots (Figure 15).

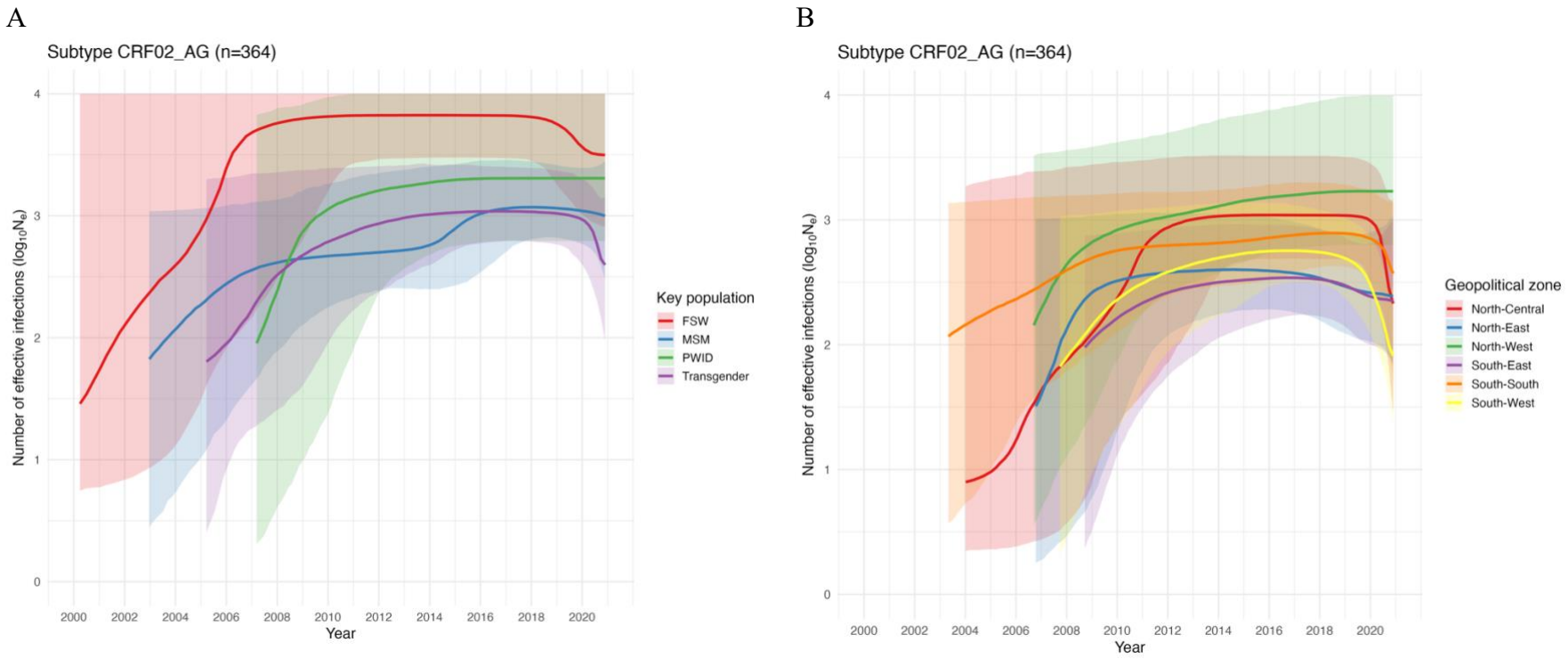


**Figure 13. HIV Subtype CRF02_AG: Estimates of median effective population sizes by A) key population groups and B) geopolitical zones; Nigerian IBBSS (2020).**

Estimates were produced using coalescent Bayesian skyline plots run with a single seed (except for the South-East, which required two seeds) for 300,000,000 Markov Chain Monte-Carlo (MCMC) chains, where effective sample sizes (ESS) exceeded the minimum acceptable threshold of 200 for all model statistics. The median effective population size is shown by the solid lines, with the 95%

highest and lowest posterior densities represented by the shaded area. Key populations stand for: Female sex workers (FSW), men who have sex with men (MSM) and people who inject drugs (PWID).

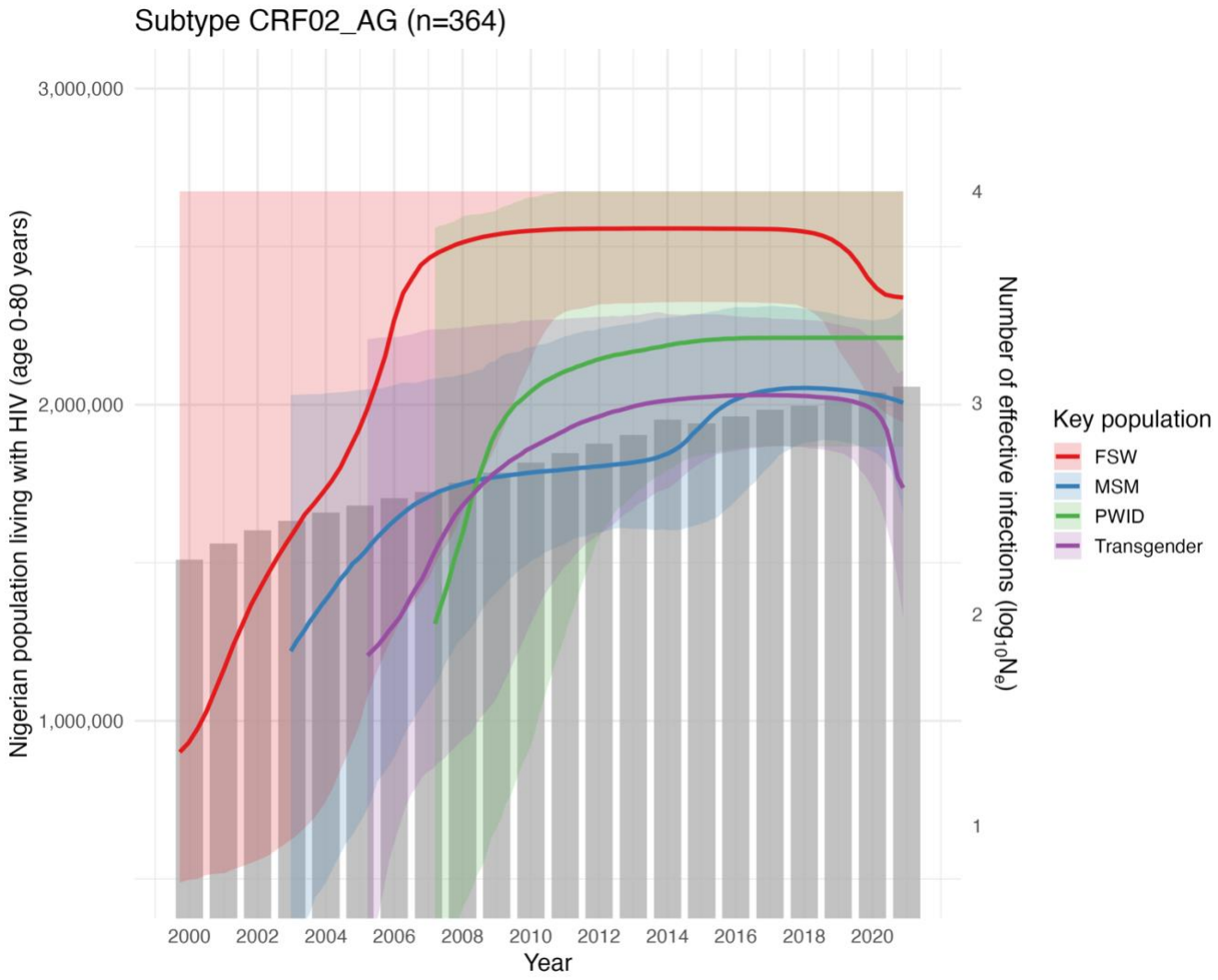


**Figure 14. HIV subtype CRF02_AG: Estimates of median effective population size among key population groups overlaid with estimated Nigerian population living with HIV; Nigerian IBBSS (2020).**

Grey columns represent Spectrum AIM (https://aim.spectrumweb.org) estimates for population living with HIV aged 0-80 years in Nigeria. Estimates were produced using coalescent Bayesian skyline plots run with a single seed for 300,000,000 Markov Chain Monte-Carlo (MCMC) chains, where effective sample sizes (ESS) exceeded the minimum acceptable threshold of 200 for all model statistics. The median effective population size is shown by the solid lines, with the 95% highest and lowest posterior densities represented by the shaded area. Key populations stand for: Female sex workers (FSW), men who have sex with men (MSM) and people who inject drugs (PWID).

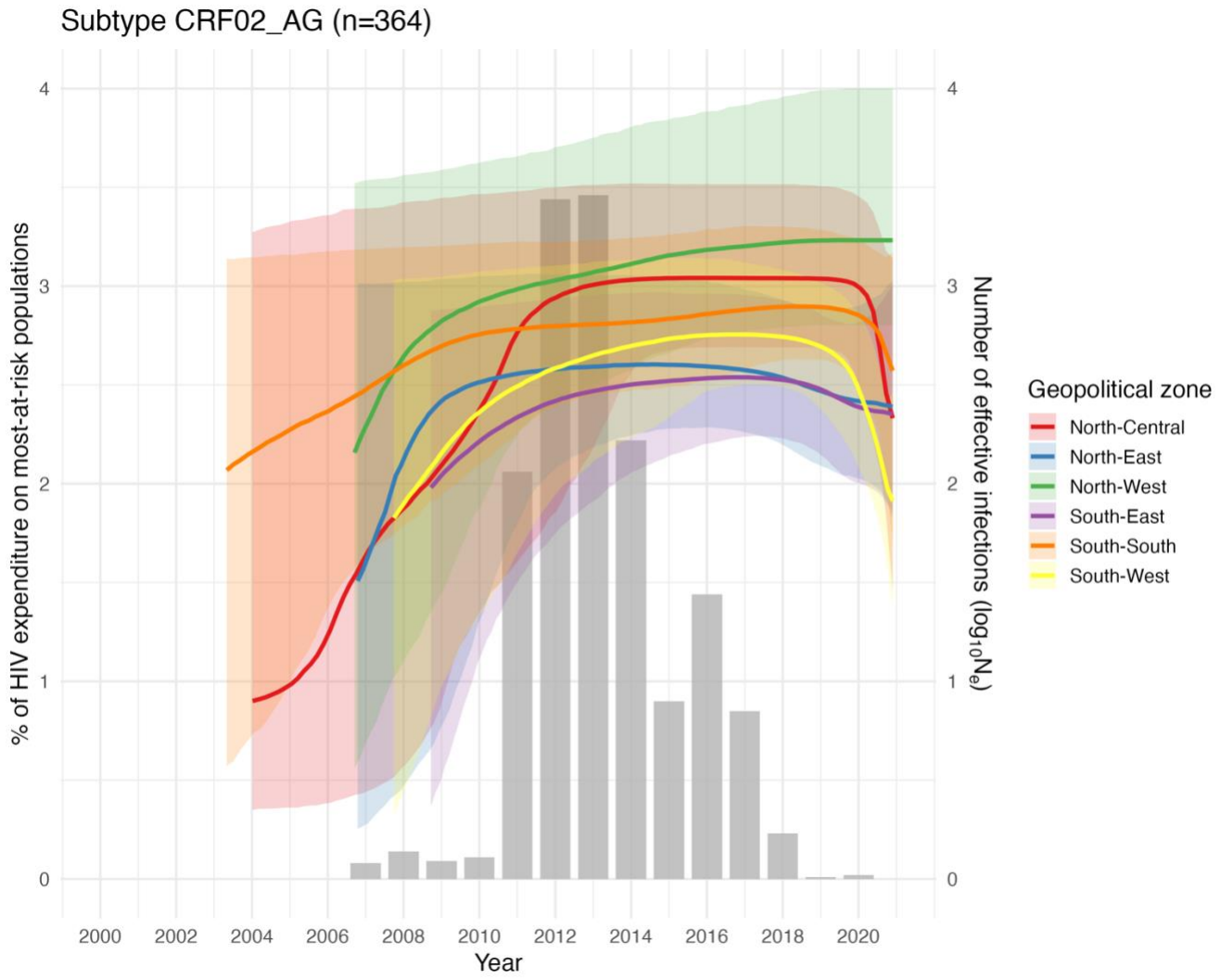


**Figure 15. HIV subtype CRF02_AG: Estimates of median effective population size by geopolitical zone overlaid with dedicated HIV spending expenditure to "most-at-risk populations"; Nigerian IBBSS (2020).**

Grey columns represent the percentage of the yearly HIV expenditure dedicated to “most-at-risk populations”, which broadly align with key population groupings. Estimates were produced using coalescent Bayesian skyline plots run with a single seed for 300,000,000 Markov Chain Monte-Carlo (MCMC) chains, where effective sample sizes (ESS) exceeded the minimum acceptable threshold of 200 for all model statistics. The median effective population size is shown by the solid lines, with the 95% highest and lowest posterior densities represented by the shaded area.

#### *4.2.3.2. Ancestral migration events*

A structured coalescent analysis was carried out to assess the spatial relationship of HIV transmission among the various key population groups and geopolitical zones included in the 2020 IBBSS. Inferred HIV ancestral migration events between key population groups and geopolitical zones for subtypes CRF02_AG and G are presented in Figures 16 and 17, and in Appendix E Tables S8 and S9, respectively.

In the key population migration model for HIV subtype CRF02_AG, the highest median number of ancestral migration events were observed from MSM to transgender people (14.03 [95% HPD: 10.51, 17.99]) and from FSW to PWID (7.53 [95% HPD: 4.82, 10.65]). This was a shared finding across the subtype G model, though both were observed at lower magnitudes (MSM to TG: 7.14 [95% HPD: 3.89, 10.87] and FSW to PWID: 4.05 [95% HPD: 0.33, 7.84]). These models differed in that the HIV subtype CRF02_AG model had a high median number of ancestral migration events from PWID to MSM (6.28 [95% HPD: 1.92, 9.85]), while the HIV subtype G model had a high median number of ancestral migration events from PWID to transgender people (4.70 [95% HPD: 0.23, 7.95]) and FSW to MSM (3.45 [95% HPD: 4.36 $x10^{-4}$, 6.77]).

In the geopolitical zone migration model for HIV subtype CRF02_AG, the highest median number of ancestral migration events was observed in the direction towards northern zones (North-East, North-Central, and North-West), originating from southern zones (South-East, South-South, South-West) (1.87 [95% HPD: 1.29, 2.55]). This was the opposite for HIV subtype G, where the highest median number of ancestral migration events was observed in the direction towards southern zones (3.68 [95% HPD: 2.33, 5.24]), having originated from northern zones.

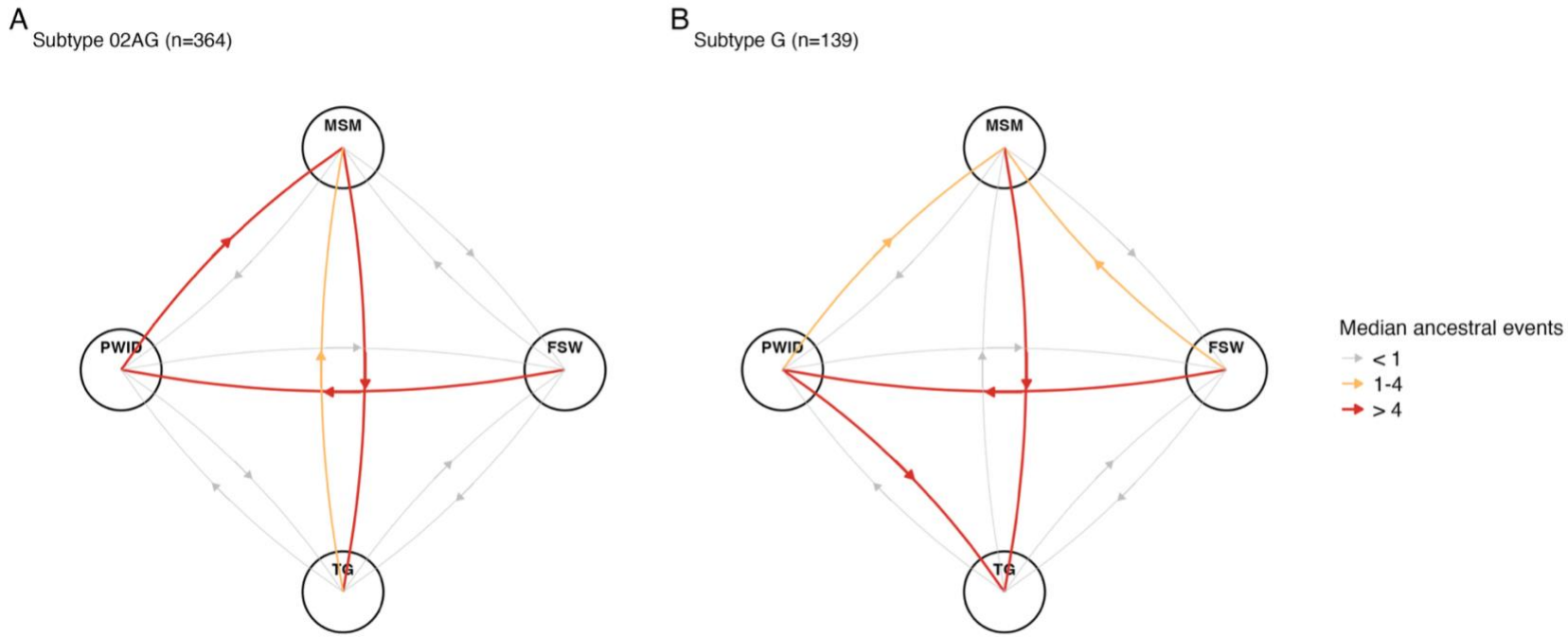


**Figure 16. Estimated number of HIV ancestral migration events between key population groups, by HIV subtype; Nigerian IBBSS (2020).**

HIV subtype CRF02_AG (panel A) and G (panel B) models were constructed using structured coalescent models with a *MultiTypeTree* prior run with two (subtype CRF02_AG) and four (subtype G) seeds for 300,000,000 Markov Chain Monte-Carlo (MCMC) chains. Effective sample size (ESS) values exceeded the minimum acceptable threshold of 200 for all model statistics (Appendix F, Figures S6, S7). Key populations stand for: Female sex workers (FSW), men who have sex with men (MSM), people who inject drugs (PWID), and transgender (TG) people.

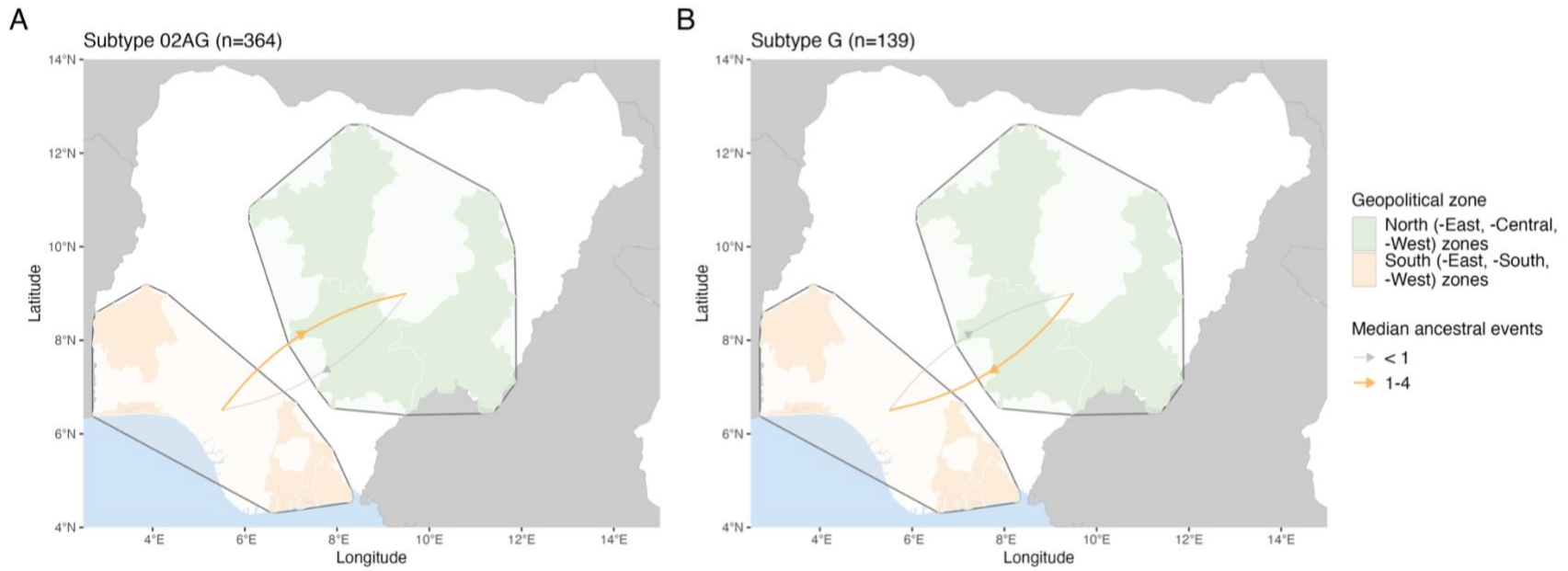


**Figure 17. Estimated number of HIV ancestral migration events between northern and southern geopolitical zones among key populations, by HIV subtype; Nigerian IBBSS (2020).**

Both HIV subtype CRF02_AG (panel A) and G (panel B) models were constructed using structured coalescent models with a *MultiTypeTree* prior run with three seeds for 300,000,000 Markov Chain Monte-Carlo (MCMC) chains. Effective sample size (ESS) values exceeded the minimum acceptable threshold of 200 for all model statistics (Appendix F, Figures S6, S7).

# CHAPTER 5 DISCUSSION

## 5.1. Determinants shaping HIV service outcomes for key populations

The narrative review aimed to identify social determinants of HIV service engagement among key populations in Nigeria across four levels of the modified social ecological model: individual, network, community, and policy. The modified social ecological model for HIV risk was developed with the argument that data on risk factors across these multiple levels should be collected routinely as part of any epidemiological episode.[29] The relevance of this framework is particularly strong in the Nigerian context, where key population groups bear a disproportionate burden of HIV incidence and prevalence relative to the general population, yet viral suppression among those diagnosed with HIV remains short of WHO targets (75.5-86.1%).[9] This reflects Nigeria's mixed epidemic status[3], and underscores the importance of understanding the conditions shaping service engagement across the full cascade of care. As Baral et al. (2013) note,

> No behaviour, policy or law, community determinant, network attribute, or individual characteristic can create infectious disease; rather these can only create conditions which either increase or decrease the probability of acquisition or onward transmission of an already prevalent disease.[29(p.4)]

Situating this review's findings within the modified social ecological model emphasizes the multi-level structural conditions shaping HIV service outcomes among key populations and shifts attention from the individual-level determinants that are frequently the target of interventions by policy-makers.[29] An important principle underlying this framework is that determinants can (and often) span multiple levels of the model, which can blur the boundaries

between levels and challenge the framing of determinants within a distinct level.[29] For example, membership in a particular group, such as a key population or religion, is registered at the individual level, but the societal exclusion and/or stigma resulting from group membership manifests at the community level. This poses practical implications for how determinants are interpreted and coded, and for how interventions are designed and targeted. Indeed, while membership in a particular group can be theorized as being a community-level structural position, they are frequently measured within studies as an individual-level characteristic.[29] Keeping this in mind, the discussion that follows treats each level of the modified social ecological model as an analytical lens, rather than as discrete categories, recognizing that the most consequential determinants for key populations in Nigeria are often those that span multiple levels or whose effects at one level are conditioned by determinants at another.

Individual-level sociodemographic characteristics were among the most consistently identified determinants of HIV service engagement across the care cascade. Higher education level,[139, 140, 143, 144, 148, 149, 154, 157, 159, 163, 167, 169] older age,[140, 144, 148, 150, 153, 154, 167, 169] and being employed[140, 164, 167] emerged as consistent facilitators of prevention, testing, and treatment outcomes across multiple key population groups and geopolitical zones. However, these individual-level characteristics may function as proxies for structural position, which lies beyond individual control. For example, educational attainment shapes health literacy, economic stability, and a person's capacity to navigate healthcare systems, but education is itself shaped by the economic circumstances, geographic location, and societal conditions a person is born into, consistent with socioecological models that situate individual attributes within broader structural contexts.[29] Therefore, framing education as an individual-level determinant risks misattributing its influence as a marker of structural advantage or disadvantage. A similar argument may apply

when considering the influence of employment status. Not being employed was reported in reviewed studies as being a barrier to PrEP uptake and continuation and a facilitator of HIV testing history,[140, 157, 164, 167] but these outcomes may be influenced by the economic instability and competing survival priorities facing unemployed individuals, rather than a lack of individual motivation. In the same vein, prior HIV and STBBI programme engagement, including a history of HIV testing,[139, 144, 154] STBBI knowledge[139, 144, 154, 169] and treatment,[154, 165] and programme enrollment,[142, 148] was consistently described as a facilitator to subsequent service engagement across the care cascade. However, this pattern likely reflects the cumulative effects of individual-, network-, community-, and policy-level conditions that facilitated engagement, rather than an individual-level measure. In this sense, prior engagement may function more as a marker of structural position, implying that individuals who have successfully navigated barriers to HIV services once are more likely to do so again. This structural reframing of individual-level determinants may also help to explain heterogeneity observed in programming outcomes by determinants at this level across study sites[140, 144, 148, 154, 163] and key population groups.[153, 157, 160, 163, 167]

Compared to other levels of the modified social ecological model, network-level determinants were less frequently discussed within the reviewed studies. This likely reflects study design priorities/limitations rather than the true importance of network-level factors to HIV service outcomes and the relative shortage of network-level determinants identified in this review should not be interpreted as evidence that such relationships are unimportant. When network-level determinants were included, they most often focused on social support provided by family and peers as a facilitator of service engagement.[144, 149, 157, 161] Among MSM and transgender people in Nigeria, the structure and characteristics of social networks are likely

shaped by the broader influence of societal norms, such as the criminalization of same-sex relationships, which in turn influence network density and size,[144, 157] disclosure patterns,[142, 144, 152, 157, 160, 161, 169] and supportive capacity of peer and family relationships.[144, 149, 157, 161]

Community-level determinants were the second most frequently identified level following the individual level, which aligns with the conceptualization of the community level as where structural conditions, such as stigma, become most tangible for individuals. Determinants at this level shape the immediate environment experienced by individuals, including settings, norms, and healthcare services, which are influenced by upstream policy conditions and downstream individual-level and network-level behaviours. For example, the criminalization and broader marginalization of key populations in Nigeria have been established as influencing institutional norms and provider behaviours encountered by individuals seeking services, which can either obstruct or facilitate engagement.[171] This was consistently reflected in the finding that provider stigma and discrimination were barriers to HIV service outcomes across the care cascade.[13, 49, 147, 151, 158, 161] Contrastingly, safety, confidentiality, and trust in the clinical encounter were facilitators.[13, 49, 158, 162] A similar pattern was observed for programme delivery, which found that programmes that better met the needs of key populations whether through outreach, peer support, wrap-around services, and key population-competent staff, were universally associated with improved HIV service outcomes.[49, 141, 145, 158, 162] As expected, inflexible, non-affirming, or insufficiently-resourced delivery models were consistently identified as barriers.[12, 13, 49, 147, 151] Geographic availability and accessibility added a further structural dimension, with greater distance to services acting as a barrier to prevention and treatment engagement, and proximity to services acting as a facilitator.[151, 158, 161, 162] Taken

together, these findings highlight that determinants at the community level serve as a critical pivot point for influencing HIV service outcomes for the better or for the worse.

Since this review was restricted to key population-containing literature, the criminalization of key population-defining behaviours is a grounding feature across all retained studies and the findings synthesized here. Within the reviewed studies, the limited number of determinants identified at the policy level (e.g., criminalization, funding cessation) were described as temporal events with a prolonged negative effect on HIV programme engagement in the country,[40, 138] rather than as having variable influence across settings. This distinguished the policy level from other levels of the modified social ecological model, where determinants showed more directional variability based on study contexts. It should be noted that most retained studies were not designed to directly assess policy effects, but instead often covered downstream effects at the community, network, and individual levels–including stigma, peer and familial support, and programme delivery. Criminalization of same-sex relationships was the most frequently discussed policy-level determinant, consistent with its long-standing influence as a barrier to advancing HIV epidemic control in Nigeria.[40, 58, 151] While the criminalization of sex work and drug use were not explicitly named in retained studies, likely because these laws were formalized in 1990 for sex work and 1989 for drug-related offenses, they are presumed to continue to play a major role in how HIV services are implemented and delivered for FSW and PWID. The cessation of aid funding in January 2025 by the US government constitutes a further policy-level determinant whose downstream effects on the network, community, and individual levels have already been observed and are expected to leave a profound impact on HIV service engagement among key populations in Nigeria.[138]

This review documented a wide range of facilitators and barriers shaping HIV service outcomes among key populations in Nigeria across prevention, testing, and treatment domains, and confirms that these determinants rarely operate in isolation across levels of the modified social ecological model. Effectively addressing HIV service engagement among key populations in Nigeria therefore requires a conscious effort to engage with determinants at all levels, with particular attention given to the structural conditions that individual-level characteristics often act as proxies for within epidemiological studies.

### 5.2. Molecular epidemiology of HIV among key populations in Nigeria

The determinants identified in Objective 1 describe the many influences on HIV service outcomes among Nigerian key populations, but on their own cannot reveal how transmission occurs or population groups are connected. Molecular surveillance offers a precise way of pinpointing active transmission areas and approximating historical transmission patterns.[19, 20] The 2020 IBBSS dataset presented an opportunity to apply novel phylogenetic and phylodynamic methods to characterize recent transmission chains and viral dynamics among key populations living with HIV in Nigeria, serving as this study's Objective 2. This study is the first, to our knowledge, to apply these methods across all Nigerian key populations and geopolitical zones, extending the body of molecular literature that was previously limited to a single key population group and/or geographical setting.[21, 25]

#### 5.2.1. Key population connectivity

Across both phylogenetic and phylodynamic methods, connectivity was concentrated within two key population pairs – MSM and transgender people, and FSW and PWID. The consistent key population signal across subtypes, despite differences in key population group composition (subtype CRF02_AG: mainly MSM and transgender people; subtype G: mainly FSW), suggests

that this connectivity reflects genuine transmission dynamics rather than being driven by sample composition alone.

In phylogenetic clusters, 26% (n=142/547) of IBBSS sequences formed 47 clusters (Figures 9-12). Aligning with the hypothesis that population-joining linkages would be formed mainly by MSM, clustering was concentrated among MSM and transgender people, who comprised 89% of clustering sequences. MSM and transgender people had over five times greater adjusted prevalence in phylogenetic clusters relative to FSW (aPR: 5.38 [95% CI: 2.87, 10.07] for MSM; aPR: 5.52 [95% CI: 2.96, 10.28] for transgender people) (Table 10), and this pairing showed the highest median number of ancestral migration events among key population groups across both HIV subtypes (14.03 [95% HPD: 10.51, 17.99] for subtype CRF02_AG; 7.14 [95% HPD: 3.89, 10.87]) for subtype G) (Table S10). This is consistent with the hypothesized relationship between ancestral migration event intensity and programmatic gaps, as inequitable programme outcomes have been well-documented among MSM and transgender people, including reduced engagement with HIV prevention and testing services.[154, 168]

MSM in Nigeria experience heightened HIV risk through the criminalization of homosexuality under the 2014 Same-Sex Marriage Prohibition Act, which is associated with an overall avoidance of healthcare by MSM.[40, 151] However, the effect of key population group on HIV service engagement is complex and variable across settings in Nigeria,[153, 157, 160, 163, 167] likely because it captures elements of network- and community-level exclusion and stigma. Nonetheless, the connectivity observed between MSM and transgender people may reflect shared legal and social environments, as the 2014 legislation has been described as an underlying negative influence on network-level conditions, including network size and density,[144, 157] level of social support,[144, 157, 161] and sexual orientation and gender identity disclosure patterns,[58, 142,

[144, 157, 169] ultimately shaping how both groups feel safe to engage, or not engage, with HIV services.[40, 151] Considering this potential for overlapping social and sexual networks under conditions of reduced public visibility,[172] paired with the observed connectivity between MSM and transgender people, it is plausible that conditions exist which perpetuate sustained, uninterrupted HIV transmission between these two groups. This interpretation should be considered alongside limitations with the operational definitions used in the IBBSS to assign MSM and transgender status, which may not have sufficiently distinguished membership between these groups.[9]

A parallel, though comparatively smaller, pattern of viral connectivity was observed between FSW and PWID. Two phylogenetic clusters comprised participants from both groups (Figures 8-12), and structured coalescent models identified ancestral migration events from FSW to PWID across HIV subtypes CRF02_AG (7.53 [95% HPD: 4.82, 10.65]) and G (4.05 [95% HPD: 0.33, 7.84]) (Figure 16, Table S10). Consistent with the hypothesized relationship between migration intensity and programmatic gaps, this connectivity may reflect overlapping community- and policy-level marginalization experienced by FSW and PWID that act as barriers to harm reduction and sex work-related programme coverage, including the criminalization of key population-defining behaviours, societal stigma, programme availability, and uneven geographical access.[4, 42, 54, 55]

More broadly, Bayesian skyline plots of the two dominant HIV subtypes among IBBSS participants living with HIV, CRF02_AG (n=364) and G (n=139), suggest that median effective population size remained elevated between 2000-2020 across all key population groups (Figures 14 and S5). Consistent with the hypothesis that epidemic trajectories would differ substantially by key population, distinct phases of exponential growth and deceleration were observed across

all four key population groups. However, the timing of exponential growth and deceleration differed between groups, and the relative magnitude of epidemic trajectories did not consistently favour MSM and transgender people as hypothesized. Bayesian skyline plots presented in this study suggest that effective population size among FSW was the first to decelerate, around 2008, followed by MSM and transgender people, and finally PWID (Figure 13). This pattern is consistent with differences in programme reach and retention across key populations broadly within the Nigerian context.[153, 157, 160, 163, 167] FSW-specific location typologies have historically been mapped and documented more extensively than those of MSM or PWID in Nigeria, possibly due to their higher public visibility as client-facing facilities,[172] which might explain FSW being targeted and reached earlier and more consistently by key population HIV programming relative to other groups.

HIV epidemic trajectories among key population groups broadly aligned with rising national estimates of people living with HIV, from approximately 450,000 in 2000 to approximately 2,400,000 by 2020 (Figure 14).[173] This is consistent with evidence that HIV transmission chains in the country do not reflect simple "source-sink" relationships, but instead cross back and forth between the broader adult population and key population groups.[21] The national rise in HIV infections occurred alongside a sustained increase in national ART coverage, from 19% in 2010 to 60% in 2020 among Nigerians of all ages,[174] yet model-derived estimates suggest that relative transmission intensity among key population groups continued to rise over this same period. This could reflect a lag between epidemic peaks and policy response, since ART scale-up efforts rarely reach full scale and intensity immediately, or it could mean that transmission would have risen even further without concurrent ART expansion. Since regular, iterative reporting of key population-stratified ART coverage data are unavailable (as the

four previous IBBSS rounds were conducted too infrequently), this national trend cannot confirm whether ART scale-up reached key populations at comparable rates. Regardless, the persistence of elevated effective population sizes through this period supports the case for key population-specific programming, particularly where HIV resource allocation can risk shifting away from key populations once general population indicators appear to improve.[5, 175]

5.2.2. Geopolitical zone connectivity

Geopolitical zone emerged as a key variable shaping HIV transmission in Nigeria, coinciding with previously reported variation in key population programme coverage, location typology, and service reach across Nigeria's zones.[9, 16, 109, 129] This study reported HIV sequences from the South-West (aPR: 1.88 [95% CI: 1.13, 3.12]) and North-East (aPR: 1.91 [95% CI: 1.07, 3.41]) zones having higher adjusted prevalence in phylogenetic clusters compared to the North-Central zone (Table 10). The South-West zone is home to large urban centres, such as Lagos and Ibadan, which concentrate HIV programme infrastructure and service availability, in addition to key population densities. This concentration may facilitate greater and likely more complex network-level sexual or injecting overlap (e.g., multiple, concurrent partnerships), helping to explain why previous Nigerian studies have found urban settings to be barriers to HIV service utilization compared to semi-urban and rural areas.[153]

In contrast to the hypothesized pattern of earlier growth in southern zones, Bayesian skyline plot results revealed a more heterogeneous timing pattern, with early growth phases observed in both northern (North-Central) and southern (South-South) zones as early as 2004, suggesting that phases of epidemic growth across geopolitical zones did not follow a consistent pattern (Figure 13). A broad pattern of overlap was also observed between key population-directed HIV expenditure (public, private, and donor) and epidemic trajectories across

geopolitical zones, with the percentage of national HIV expenditure directed toward key population groups peaking at 3.46% in 2014,[133] which is approximately the period when effective population size estimates began declining in the North-Central, North-East, and South-South zones (Figure 15). Though it cannot confirm a relationship, the timing is consistent with more effective translation of policy-level funding into community-level programme coverage in these zones, which has been explored by previous HIV phylodynamic studies conducted at a programme level in South Africa and Ukraine.[84, 85] In contrast, the epidemics in North-West, South-East, and South-West zones continue to rise after a peak in expenditure, which may reflect uneven translation of funding into programme coverage across zones, consistent with qualitative evidence that Nigerian HIV budget allocation has historically prioritized geopolitical representation rather than geographic prioritization.[176]

Phylodynamic modelling of subtype CRF02_AG, comprised predominantly of MSM and transgender sequences, identified ancestral migration events directed towards northern zones (1.87 [95% HPD: 1.29, 2.55]), likely reflecting migration towards the national capital of Abuja (North-Central zone) (Table S11). Contrastingly, findings from subtype G phylodynamic models concentrate ancestral migration events towards southern geopolitical zones (3.68 [95% HPD: 2.33, 5.24]). Increased ancestral migration events between geopolitical zones was hypothesized for geographies facing gaps in HIV programme coverage, which may be true of both northern and southern zones.

Internal migration trends in Nigeria are known to be complex and influenced by a combined impact of economic and geopolitical factors, highlighted by a 2021 United Nations report.[177] As expected, Lagos (South-West) and Abuja (North-Central) were reported as major destinations for internal migrants, but migratory patterns were noted to be more complicated than

people moving towards major economic hubs, and displayed heterogeneity even between men and women.[177] The report also hypothesized conflict to be a driver of migration in Nigeria, citing the Boko Haram crisis in the North-East zone as having displaced over two million people,[178, 179] driving an influx of internally displaced persons and disrupting healthcare, education, and socioeconomic activities in the North-East, North-Central, and North-West zones.[180] Displacement resulting from conflict can have ripple effects across social ecological levels, disrupting network-level social ties and sexual norms and community-level institutions of protection[181] and having a profound impact on HIV epidemic control. While internal migration in the country creates socioeconomic development opportunities – including the formation of new network-level ties, increased economic growth, and improved living standards – they can also create challenges to community-level infrastructure, namely healthcare and education,[177] and likely HIV programming.

Given the large variation in key population size estimates, HIV prevalence, location typology utilization, and programme reach between Nigeria's geopolitical zones,[9, 16, 109, 129] it is plausible that the geopolitical zone variable also reflected the influence of other measured and unmeasured variables in the model. For example, despite its established relevance to key population programming in Nigeria,[108, 172] this study reported location typology to have a null effect as a predictor of phylogenetic cluster membership. This also may be further explained by the treatment of location typology as a static variable, rather than transient and shifting in response to policing, displacement, or structural changes in the local economy.[172] It also may be explained by differences in location typology composition between key population groups, outlined in supplementary materials (Appendix E, Table S6). Venue-based interventions have shown promise among key populations in Kenya, Malawi, and Angola,[182, 183] though these

interventions rely on effective location mapping, which is challenged by the reduced public visibility of MSM and transgender people using conventional sampling methods.[172] Realizing the potential of venue-based HIV programming in Nigeria will require sustained community engagement to identify undocumented location typologies and strengthen the reach of these interventions.

Similar to location typology, the null results reported in this study for programme outreach, availability, and utilization within the past year may reflect the influence of key population group membership and geopolitical zone on programme coverage, rather than a true absence of effect on phylogenetic clustering. This aligns with previous reports that engagement by Nigerian key populations with HIV services is shaped as much by the reach and characteristics of local programming at community[12, 13, 49, 141, 145, 147, 151, 155, 158, 161, 162] and policy[40, 58, 137, 138, 151] levels. Indeed, heterogeneity has been previously observed across the four dimensions of HIV programme coverage—required, availability, contact, and utilization–among IBBSS participants.[109] It is also possible that the transmission partners linking a given participant to others were not captured by this study's sampling approach or were virally suppressed, in which case null results for programme engagement variables may reflect incomplete network sampling rather than a true absence of effect. Both these interpretations suggest that the null result should not be interpreted as evidence against a meaningful role for programme engagement in HIV transmission dynamics among Nigerian key populations.

Ultimately, the molecular findings from phylogenetic and phylodynamic methods indicate that HIV transmission among Nigerian key populations is shaped jointly by key population group membership and geopolitical zone, which reflect the many individual-, network-, community-, and policy-level conditions identified in this study's Objective 1.

## 5.3. Study Strengths and Limitations

### 5.3.1. Strengths

By incorporating the modified social ecological model as an organizational framework, as well as being guided by a programme science approach, Objective 1 summarizes the multi-level determinants influencing HIV programme utilization across Nigerian key populations. This design has yielded granularity in its findings, identifying facilitators and determinants at each level (i.e., individual, network, community, and policy), key population group, and Nigerian geopolitical zone. This increased precision is well-positioned to produce insights that can be fed back into programmes as recommendations to improve outreach and care for these populations. Additional strengths of Objective 1's narrative review include its ability to pull many pieces of information cohesively,[101] presenting a broad perspective and description of the last 20 years of the Nigerian HIV epidemic among key populations, in addition to its management and responses. Since this review was intended to inform Objective 2, a narrative review was best suited to generate a rich and comprehensive summary of HIV among Nigeria's key populations to contextualize findings of the molecular epidemiological analyses, in addition to being flexible and practical.[100]

Strengths of Objective 2's quantitative analysis include its large sample size, which enhances statistical power, and its feasibility as a secondary analysis (from a cost and time perspective). The sampling methods from the primary IBBSS ensured a strong representation of key populations, notably transgender people, which allowed the current study to examine the overlap between multiple key populations and geographies. Indeed, this was the first population-based survey to include transgender people in the country. By using HIV sequences from participants with detectable viral loads (i.e., HIV-viraemic), the current study provides

information on individuals not receiving or not adhering to antiretroviral therapy and can generate insights for how service coverage and reach can be improved. Further, by combining phylogenetic analysis with behavioural surveys, patterns can be revealed that are not visible through behavioural data alone, particularly if stigmatized or criminalized behaviours are underreported, and health-seeking behaviours are overreported. Similarly, phylodynamics integrates genetic, epidemiological, and temporal data to reveal transmission and migration patterns that would otherwise be difficult to observe.

Further, Objective 2's analysis is embedded within the longstanding partnerships between the IGPH, NACA, and WACPHD. These collaborations are grounded in mutual respect, humility, and shared decision-making and accountability. While my role as an MSc student is limited as per graduate student constraints (e.g., timeline, funding, etc.), this study is part of a broader programme science initiative driven by partner expertise and interests. Although the training-intensive and technical nature of the molecular epidemiological methods in this study may risk appearing to undervalue these partnerships, this work and its research questions originated at the request of our Nigerian partners. Further, its analysis and interpretation have been guided by their perspectives through ongoing virtual engagements, ensuring that these findings are understood through the local expertise that our collaborators provide.

### 5.3.2. Limitations

The narrative review associated with Objective 1 carries several inherent limitations. These limitations were partly mitigated by documenting the review rationale, search terms, inclusion/exclusion criteria, a reflexivity statement by the researcher, and full analytical details.[100] However, having a single reviewer perform the screening and extraction remains a major limitation of this objective. Additionally, a majority of retained studies encompassed

several key populations and geopolitical zones, and presented their findings in a consolidated manner, which limited the discussion of determinants influencing HIV programme engagement on a per-group or per-zone basis. Since Objective 1 was intended to inform Objective 2, this limitation carried through to the molecular epidemiological analyses and how its findings could be contextualized.

The quantitative analysis associated with Objective 2 is not without its limitations. First, the molecular signals described here are driven by sampling methodology and sample recovery from DBS specimens. Although the sample size was large by the standards of a cross-sectional molecular study, it did not permit stratification within key population groups. The use of operational definitions, rather than self-identification, to classify MSM and transgender participants likely introduced misclassification between these groups and influenced the observed viral connectivity. Conventional sampling methods likely captured a more socially visible demographic within each key population, and prioritizing key populations over network-based sampling may explain the shortage of FSW and PWID present in phylogenetic clusters, who may have been more likely to form heterosexual linkages with partners outside the IBBSS. Second, the IBBSS is designed with the intention of capturing a representative sample of each entire key population group at "high risk" of HIV infection, not necessarily participants that are unengaged or engaged with care. HIV-negative participants, who comprise most of the respondents, contribute no sequence data, meaning the sample does not represent the full at-risk population. It also means that the study sample is biased by people who are more likely to be reached by the IBBSS sampling methods and further restricted by those who are HIV antibody-positive and have a detectable viral load, which may not accurate reflect the sociodemographic and programmatic realities of the broader key population group. As a secondary analysis of

existing survey data, variables relevant to molecular methods may have not been collected by design, missing data were present, and self-reported measures are subject to social desirability and recall biases. Third, the cross-sectional study design prevents establishing causality or temporal relationships between sociodemographic or behavioural data and cluster membership. Fourth, the arbitrary threshold of 0.02 substitutions per site used to define phylogenetic clusters may have missed some phylogenetic linkages, though phylogenetic clusters have been shown to align closely with characterized transmission chains.[184] Fifth, parameters generated from phylodynamic models, such as median number of effective infections and ancestral migration rates, are model-derived estimates and not direct measurements. Like all modeling approaches, these parameters are heavily reliant on a set of assumptions that can significantly affect the results if violated. Several of these assumptions were unable to be mitigated due to the design and sampling of the IBBSS itself, including random sampling of the entire population, a closed population with no external introductions, discrete and accurate group assignment, and all relevant groups being sampled (e.g., clients and partners). Phylodynamic models were also limited to HIV subtypes G and CRF02_AG and may not represent other epidemic strains,[21] though these subtypes account for an estimated 22-50% and 19-60% of Nigerian HIV infections, [24, 185] respectively. Finally, though methodologically consistent, infrequent IBBSS rounds (2007, 2011, 2014, 2020) constrained the ability to contextualize temporal phylodynamic findings, and although national coverage trends are presented as context instead, these also cannot serve as a direct comparison.

# CHAPTER 6 CONCLUSIONS

## 6.1. Knowledge translation

A key intent of this study was to produce informative and actionable insights, which is inherent to a programme science approach. Molecular epidemiology has been previously criticized for requiring specialized expertise, particularly professionals with the technical skills and broader contextual understanding, so that findings and any ethical implications are interpreted appropriately.[186] As a result, phylogenetic and phylodynamic studies may remain siloed within academic circles and generate few actionable insights. By engaging both academic and policy-making communities, this study sought to ensure its findings can lead to positive change by addressing the needs and objectives of our research partners.

Debriefing sessions with the IBBSS team, consisting of a national government agency (NACA) and a non-governmental organization with community ties (WACPHD), occurred in December 2025 and June 2026 to help contextualize and translate findings into recommendations. These meetings were instrumental in providing local context, including the importance of geopolitical zones from a policy and programming perspective, the consolidation of northern and southern geopolitical zones to strengthen phylodynamic models, as well as flagging the potential for misclassification between MSM and transgender participants in the IBBSS based on operational definitions.

Dissemination with the scientific community with Nigerian co-authors occurred at the Canadian Association for HIV/AIDS Research (April 2025 and 2026), the International Union for Sexually Transmitted Diseases Research STI & HIV World Congress (July 2025) and is planned at the World Congress of the International Union against Sexually Transmitted Infections (October 2026). Further academic dissemination is planned through publication of

Objective 2's molecular epidemiological analysis. Dissemination through peer-reviewed publications strengthens the visibility and credibility of the IBBSS, providing documented evidence to support future funding and sustainability of key population surveillance. In the event of publication, sequencing data will not be publicly released to minimize any social harm resulting from the study, given the well-documented ethical concerns regarding the use of HIV genotyping data without patient consent/knowledge.[187, 188]

### 6.2. Future considerations

The debriefing sessions with IBBSS partners coincided with the planning for Nigeria's next key population IBBSS. Although these data were presented to the larger team nearly six years after the primary study's data collection, it was fortunate they could be shared prior to the next survey's implementation to illustrate what molecular insights can contribute to the country's HIV response. However, incorporating phylogenetics and phylodynamics as a secondary analysis within the larger IBBSS will likely continue to face inherent constraints in the extent of information they can provide. The most informative and granular phylodynamic studies are typically conducted longitudinally and collected from participants engaged within an existing programme that is offered in a specific location,[21, 84, 85] where programmatic modifications are well-characterized and can be examined using trends in viral dynamics. Studies designed with this specificity are better suited to answer targeted phylogenetic and phylodynamic questions, and any obtained inferences are more likely to carry direct implications for planning and programming. However, given its feasibility, the secondary study design described here is likely how molecular epidemiology will continue to be conducted within the country, so this redesign is unlikely to occur.

That said, future IBBSS operational definitions and questionnaires could be tailored to better contextualize molecular findings. Key population groups are a critical conceptual component of the HIV response in sub-Saharan Africa,[5, 175] including Nigeria, yet the distinction between MSM and transgender people can be difficult to operationalize while gender-affirming care remains largely inaccessible.[189] Future rounds could move toward self-identification rather than assigned key population membership, which might help to address the consolidation of transgender women with MSM that has been described elsewhere in the sub-Saharan African literature, despite these groups facing distinct social contexts and barriers to HIV care that warrant differentiated, rights-affirming approaches.[190, 191] Location typology represents another important, albeit methodologically challenging, contextual factor for HIV epidemic control in Nigeria that has previously been leveraged to expand outreach and programming opportunities for FSW specifically.[192] Within the IBBSS, its assignment based on survey recruitment location rather than participant behaviour limits its utility, given that location typology is likely fluid over time even within an individual. Asking respondents which location typology they frequent the most, or which prevention services (e.g., condoms and lubricant, HIV rapid testing, etc.) are available there, could strengthen this measure in future rounds. Ultimately, only our Nigerian partners are positioned to answer if molecular analyses such as those described here are a worthwhile investment for future IBBSS.

### 6.3. Concluding remarks

In conclusion, this study combined a narrative review, phylogenetic clustering, and Bayesian phylodynamic modelling to augment and triangulate findings from a cross-sectional IBBSS, yielding cross-cutting insights that no single method could achieve alone. While the 2020 IBBSS questionnaire offers limited insight into incident infections, epidemic history, or transmission

dynamics, molecular epidemiology addressed some of these gaps. By drawing on HIV sequences from participants with detectable viral loads, this study provided information on individuals not receiving or adhering to ART drugs, who are of the greatest public health priority. This is particularly informative since the IBBSS sampling methodology is intended to reach individuals at "high risk" of HIV infection, meaning our sequence dataset may represent ongoing, uninterrupted transmission chains and be used to characterize groups burdened by high rates of transmission. Additionally, phylodynamic analyses incorporate the element of time through a molecular clock, allowing epidemic trajectories to be reconstructed years before the survey was conducted. This temporal dimension allowed historical trends in transmission dynamics to be reconstructed from a cross-sectional dataset that would otherwise only reflect a single point in time.

The behavioural and structural determinants identified in Objective 1's narrative review illustrate the conditions across levels of the modified social ecological model under which HIV transmission is enabled and risk is perpetuated, including social position, stigma, programme design and delivery, and criminalization. These influences create the network- and community-level conditions that Objective 2's phylogenetic clusters and phylodynamic models uncovered. Both phylogenetic and phylodynamic methods converge on the same pattern from independent angles, which is that key population groups and geopolitical zones showed heterogeneity in network overlap and degrees of viral connectivity. This molecular evidence signals that HIV transmission among key populations in Nigeria is not contained within discrete group silos or geographic boundaries and instead cuts across both populations and geopolitical zones. This is an especially critical finding given Nigeria's mixed epidemic status, where HIV burden is

concentrated among key populations and the trajectory of the broader epidemic in the country is dependent on programming reaching key population groups.[3-5]

As national HIV funding moves towards integration due to pressure from drastic US funding cuts,[193, 194] this analysis provides supporting epidemiological evidence that key population groups in Nigeria are connected and may be well-suited to cross-population services. Based on the evidence provided here, HIV programming that isolates key population groups or geopolitical zones from one another risks missing part of the picture of HIV transmission in Nigeria. If programming fails to reach a specific group or zone, this may create a gap that affects other connected populations. Integrating phylogenetic and phylodynamic findings with individual-, network-, community-, and policy-level contexts identified through this study acts as a safeguard against over-interpreting molecular signals and helps resist stigmatizing narratives, while strengthening the relevance for programme planning and implementation. Sustained, integrated HIV responses that engage all key populations across geopolitical zones are therefore essential to the overall effectiveness of HIV epidemic control in Nigeria.

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# APPENDIX A: HREB Certificate of Final Approval (4429:03/03/2026-03/03/2027)

RITHIM

Research Improvements Through
Harmonization in Manitoba
400-500 Portage Avenue
Winnipeg, MB R3C 3X1

**RITHIM APPROVAL**
Initial RITHIM Application

4 March 2026

**Principal Investigator:** Miss Stephanie Melnychuk
**Advisor:** Dr Souradet Shaw
**Harmony Project ID:** 4429
**Project Title:** Social and Molecular Epidemiology of HIV Among Key Populations in Nigeria: Linking Transmission Insights to Targeted Prevention

**Sponsor:** University of Manitoba, College of Community and Global Health
**Sponsor Protocol ID:** N/A

Thank you for your submission of 02/Mar/2026 19:48 The respective review decisions are documented below.

Committee for Harmonized Health Impact, Privacy, and Ethics Review (CHIPER)
**Board:** HREB
**Review Type:** Delegated
**Approval Date:** 03/Mar/2026
**Expiry Date:** 03/Mar/2027

The application was approved.

**Signed by:**

Ms. Shelly Rempel-Rossum 03/Mar/2026 21:26
CHIPER HREB Vice-Chair

*CHIPER has reviewed the above-named research project and has found it to be acceptable on ethical grounds for research involving human participants. CHIPER is constituted and operates in accordance with the current Tri-Council Policy Statement: Ethical Conduct for Research Involving Humans and the applicable laws and regulations of Manitoba.*

*In respect to clinical trials, CHIPER complies with the membership requirements for Research Ethics Boards defined in Division 5 of the Food and Drug Regulations, Part 4 of the Natural Health Products Regulations, and the Clinical Trials for Medical Devices and Drugs Relating to COVID-19 Regulations of Canada and carries out its functions in a manner consistent with Good Clinical Practices.*

*OHRP IRB Registration: IRB00012696*

**APPROVED DOCUMENTS:**
Protocol

| Document Name | Document Version | Document Date |
|---|---|---|
| Thesis proposal | 4 | 19/Dec/2025 |

**CONFLICT OF INTEREST**
Any Principal or Co-Investigators of this research project who are members of CHIPER did not participate in the review or voting of this project.

**CONDITIONS OF APPROVAL**
- Approval is granted for the research and purposes described in the application form and supporting documents only.
- Approval is contingent on compliance with any First Nations, Métis, and/or Inuit research approval(s) applicable for the project Any modification to the application, protocol or research materials must be submitted for approval prior to implementation.
- The Principal Investigator has the responsibility for any other administrative or regulatory approvals that may pertain to this research project and for ensuring that the authorized research is carried out in accordance with governing law.
- Researcher agreement(s) may need to be executed with the relevant trustee(s) before work on this project can commence.

Page 1 of 2

## APPENDIX B: HREB Certificate of Final Approval (HS23933[H2020:231])

University of Manitoba | Research Ethics and Compliance

Research Ethics Bannatyne
P126-770 Bannatyne Avenue
Winnipeg, MB R3E 0W3
T: 204 789 3255
F: 204 789 3414
bannreb@umanitoba.ca

# HEALTH RESEARCH ETHICS BOARD (HREB)

## CERTIFICATE OF ANNUAL APPROVAL

| PRINCIPAL INVESTIGATOR: | INSTITUTION/DEPARTMENT: | ETHICS #: |
|---|---|---|
| Dr. James Blanchard | U of M/Community Health Sciences | HS23933 (H2020:231) |
| **HREB MEETING DATE (If applicable):** | **APPROVAL DATE:** | **EXPIRY DATE:** |
| NA | May 12, 2025 | **May 25, 2026** |
| **STUDENT PRINCIPAL INVESTIGATOR SUPERVISOR (If applicable):** | | |
| NA | | |

| PROTOCOL NUMBER: | PROJECT OR PROTOCOL TITLE: |
|---|---|
| NA | Engagement of the University of Manitoba as a technical support organization to the National Agency for the Control of AIDS (NACA, Nigeria) for Implementation of the Integrated Biobehavioural Sentinel Surveillance (IBBSS) |
| **SPONSORING AGENCIES, FUNDING AGENCIES AND/OR COORDINATING GROUPS:** | |
| NA | |

| Submission Date of Investigator Documents: | HREB Receipt Date of Documents: |
|---|---|
| April 30, 2025 | May 9, 2025 |

**REVIEW CATEGORY OF ANNUAL REVIEW:** **Full Board Review** ☐ **Delegated Review** ☒

**THE FOLLOWING AMENDMENT(S) and DOCUMENTS ARE APPROVED FOR USE:**

| Document Name (If applicable) | Version (If applicable) | Date |
|---|---|---|

**Annual approval**

*Annual approval implies that the most recent **HREB approved** versions of the protocol, Investigator Brochures, advertisements, letters of initial contact or questionnaires, and recruitment methods, etc. are approved.*

**Consent and Assent Form(s):**

**CERTIFICATION**

The University of Manitoba (UM) Health Research Board (HREB) has reviewed the annual study status report for the research study/project named on this ***Certificate of Annual Approval*** as per the category of review listed above and was found to be acceptable on ethical grounds for research involving human participants. Annual approval was granted by the Chair or Acting Chair, UM HREB, per the response to the conditions of approval outlined during the initial review (full board or delegated) of the annual study status report.

**HREB ATTESTATION**

The University of Manitoba (UM) Health Research Board (HREB) is organized and operates according to Health Canada/ICH Good Clinical Practices, Tri-Council Policy Statement 2, and the applicable laws and regulations of Manitoba. In respect to clinical trials, the HREB complies with the membership requirements for Research Ethics Boards defined in Division 5 of the Food and Drug Regulations of Canada and carries out its functions in a manner consistent with Good Clinical Practices.

## APPENDIX C: Database search strings

| MEDLINE (via Ovid) | | | |
|---|---|---|---|
| **No.** | **Concept** | **Search string** | **Results** |
| 1 | Nigeria: key word | Nigeria/ | 37,827 |
| 2 | Nigeria: search subject | Nigeria*.mp. [mp=title, book title, abstract, original title, name of substance word, subject heading word, floating sub-heading word, keyword heading word, organism supplementary concept word, protocol supplementary concept word, rare disease supplementary concept word, unique identifier, synonyms, population supplementary concept word, anatomy supplementary concept word] | 55,780 |
| 3 | | 1 or 2 | 55,780 |
| 4 | Context: key words | (determinant* or "social determinant*" or "structural determinant*" or risk or factor* or experience* or vulnerability or stigma or discrimination or poverty or economic or criminal* or law or legislation or policy).mp. [mp=title, book title, abstract, original title, name of substance word, subject heading word, floating sub-heading word, keyword heading word, organism supplementary concept word, protocol supplementary concept word, rare disease supplementary concept word, unique identifier, synonyms, population supplementary concept word, anatomy supplementary concept word] | 11,347,178 |
| 5 | Context: search subject | social determinant of health/ or socioeconomic status/ or stigmatization/ or health inequality/ or criminalization/ or poverty/ or health disparity/ or legislation/ or vulnerable population/ | 118,222 |
| 6 | | 4 or 5 | 11,365,523 |
| 7 | HIV service: key words | ("HIV program*" or "HIV service*" or "HIV prevention" or "HIV treatment" or "harm reduction" or PrEP or PEP or ART or "antiretroviral therapy").mp. [mp=title, book title, abstract, original title, name of substance word, subject heading word, floating sub-heading word, keyword heading word, organism supplementary concept word, protocol supplementary concept word, rare disease supplementary concept word, unique identifier, synonyms, population supplementary concept word, anatomy supplementary concept word] | 302,144 |

| | | | |
|---|---|---|---|
| 8 | HIV service: search subject | human immunodeficiency virus infection/ or antiretroviral therapy/ or preexposure prophylaxis/ or HIV prevention/ or harm reduction/ | 5,053 |
| 9 | | 7 or 8 | 302,144 |
| 10 | Key population: key words | (MSM or gbMSM or "men who have sex with men" or gay or bisexual or FSW or "female sex worker*" or "sex work*" or PWID or "people who inject drugs" or "injection drug user*" or IDU or transgender or trans or "gender diverse" or "key population*").mp. [mp=title, book title, abstract, original title, name of substance word, subject heading word, floating sub-heading word, keyword heading word, organism supplementary concept word, protocol supplementary concept word, rare disease supplementary concept word, unique identifier, synonyms, population supplementary concept word, anatomy supplementary concept word] | 286,708 |
| 11 | Key population: search subject | men who have sex with men/ or sex worker/ or injection drug user/ or transgender/ | 26,531 |
| 12 | | 10 or 11 | 290,773 |
| 13 | | 3 and 6 and 9 and 12 | 144 |
| 14 | | 13 limit=”2005 to 2025” | 138 |

| **Embase (via Ovid)** | | | |
|---|---|---|---|
| **No.** | **Concept** | **Search string** | **Results** |
| 1 | Nigeria: key word | Nigeria/ | 53,152 |
| 2 | Nigeria: search subject | Nigeria*.mp. [mp=title, book title, abstract, original title, name of substance word, subject heading word, floating sub-heading word, keyword heading word, organism supplementary concept word, protocol supplementary concept word, rare disease supplementary concept word, unique identifier, synonyms, population supplementary concept word, anatomy supplementary concept word] | 68,359 |
| 3 | | 1 or 2 | 68,359 |
| 4 | Context: key words | (determinant* or "social determinant*" or "structural determinant*" or risk or factor* or experience* or vulnerability or stigma or discrimination or poverty or economic or criminal* or law or legislation or policy).mp. | 14,466,349 |

| | | | |
|---|---|---|---|
| | | [mp=title, book title, abstract, original title, name of substance word, subject heading word, floating sub-heading word, keyword heading word, organism supplementary concept word, protocol supplementary concept word, rare disease supplementary concept word, unique identifier, synonyms, population supplementary concept word, anatomy supplementary concept word] | |
| 5 | Context: search subject | social determinant of health/ or socioeconomic status/ or stigmatization/ or health inequality/ or criminalization/ or poverty/ or health disparity/ or legislation/ or vulnerable population/ | 407,267 |
| 6 | | 4 or 5 | 14,528,102 |
| 7 | HIV service: key words | ("HIV program*" or "HIV service*" or "HIV prevention" or "HIV treatment" or "harm reduction" or PrEP or PEP or ART or "antiretroviral therapy").mp. [mp=title, book title, abstract, original title, name of substance word, subject heading word, floating sub-heading word, keyword heading word, organism supplementary concept word, protocol supplementary concept word, rare disease supplementary concept word, unique identifier, synonyms, population supplementary concept word, anatomy supplementary concept word] | 466,371 |
| 8 | HIV service: search subject | human immunodeficiency virus infection/ or antiretroviral therapy/ or preexposure prophylaxis/ or HIV prevention/ or harm reduction/ | 374,543 |
| 9 | | 7 or 8 | 707,572 |
| 10 | Key population: key words | (MSM or gbMSM or "men who have sex with men" or gay or bisexual or FSW or "female sex worker*" or "sex work*" or PWID or "people who inject drugs" or "injection drug user*" or IDU or transgender or trans or "gender diverse" or "key population*").mp. [mp=title, book title, abstract, original title, name of substance word, subject heading word, floating sub-heading word, keyword heading word, organism supplementary concept word, protocol supplementary concept word, rare disease supplementary concept word, unique identifier, synonyms, population supplementary concept word, anatomy supplementary concept word] | 316,039 |
| 11 | Key population: search subject | men who have sex with men/ or sex worker/ or injection drug user/ or transgender/ | 46,212 |
| 12 | | 10 or 11 | 316,039 |
| 13 | | 3 and 6 and 9 and 12 | 355 |

| | | | |
|---|---|---|---|
| 14 | | Limit 13 to yr=”2005 – 2025” | 336 |

| Global Health (via Ovid) | | | |
|---|---|---|---|
| **No.** | **Concept** | **Search string** | **Results** |
| 1 | Nigeria: key word | Nigeria/ | 76,518 |
| 2 | Nigeria: search subject | Nigeria*.mp. [mp=title, book title, abstract, original title, name of substance word, subject heading word, floating sub-heading word, keyword heading word, organism supplementary concept word, protocol supplementary concept word, rare disease supplementary concept word, unique identifier, synonyms, population supplementary concept word, anatomy supplementary concept word] | 79,346 |
| 3 | | 1 or 2 | 79,346 |
| 4 | Context: key words | (determinant* or "social determinant*" or "structural determinant*" or risk or factor* or experience* or vulnerability or stigma or discrimination or poverty or economic or criminal* or law or legislation or policy).mp. [mp=title, book title, abstract, original title, name of substance word, subject heading word, floating sub-heading word, keyword heading word, organism supplementary concept word, protocol supplementary concept word, rare disease supplementary concept word, unique identifier, synonyms, population supplementary concept word, anatomy supplementary concept word] | 2,190,729 |
| 5 | Context: search subject | social determinant of health/ or socioeconomic status/ or stigmatization/ or health inequality/ or criminalization/ or poverty/ or health disparity/ or legislation/ or vulnerable population/ | 110,853 |
| 6 | | 4 or 5 | 2,204,087 |
| 7 | HIV service: key words | ("HIV program*" or "HIV service*" or "HIV prevention" or "HIV treatment" or "harm reduction" or PrEP or PEP or ART or "antiretroviral therapy").mp. [mp=title, book title, abstract, original title, name of substance word, subject heading word, floating sub-heading word, keyword heading word, organism supplementary concept word, protocol supplementary concept word, rare disease supplementary concept word, unique identifier, synonyms, population supplementary concept word, anatomy supplementary concept word] | 102,665 |

| | | | |
|---|---|---|---|
| 8 | HIV service: search subject | human immunodeficiency virus infection/ or antiretroviral therapy/ or preexposure prophylaxis/ or HIV prevention/ or harm reduction/ | 233,460 |
| 9 | | 7 or 8 | 262,870 |
| 10 | Key population: key words | (MSM or gbMSM or "men who have sex with men" or gay or bisexual or FSW or "female sex worker*" or "sex work*" or PWID or "people who inject drugs" or "injection drug user*" or IDU or transgender or trans or "gender diverse" or "key population*").mp. [mp=title, book title, abstract, original title, name of substance word, subject heading word, floating sub-heading word, keyword heading word, organism supplementary concept word, protocol supplementary concept word, rare disease supplementary concept word, unique identifier, synonyms, population supplementary concept word, anatomy supplementary concept word] | 68,615 |
| 11 | Key population: search subject | men who have sex with men/ or sex worker/ or injection drug user/ or transgender/ | 15,604 |
| 12 | | 10 or 11 | 68,615 |
| 13 | | 3 and 6 and 9 and 12 | 318 |
| 14 | | Limit 13 to yr=”2005 – 2025” | 295 |

| **CINAHL (via EbscoHost)** | | | |
|---|---|---|---|
| **No.** | **Concept** | **Search string** | **Results** |
| 1 | Nigeria: key words | Nigeria* | 13,725 |
| 2 | Nigeria: search subject | MH "Nigeria*" | 10,575 |
| 3 | | 1 OR 2 | 13,725 |
| 4 | Context: key words | (determinant* OR "social determinant*" OR "structural determinant*" OR risk or factor* OR experience* OR vulnerability OR stigma OR discrimination OR poverty OR economic OR criminal* OR law OR legislation OR policy) | 2,951,548 |

| | | | |
|---|---|---|---|
| 5 | Context: search subject | ((MH "social determinant of health") OR (MH "socioeconomic status") OR (MH stigmatization) OR (MH "health inequality") OR (MH criminalization) OR (MH poverty) OR (MH "health disparity") OR (MH legislation) OR (MH "vulnerable population")) | 46,871 |
| 6 | | 4 OR 5 | 2,951,548 |
| 7 | HIV service: key words | ("HIV program*" OR "HIV service*" OR "HIV prevention" OR "HIV treatment" OR "harm reduction" OR PrEP OR PEP OR ART OR "antiretroviral therapy") | 92,919 |
| 8 | HIV service: search subject | ((MH "human immunodeficiency virus infection") OR (MH HIV) OR (MH "antiretroviral therapy") OR (MH "preexposure prophylaxis") OR (MH "HIV prevention") OR (MH "harm reduction")) | 6,710 |
| 9 | | 7 OR 8 | 92,919 |
| 10 | Key population: key words | (MSM OR gbMSM OR "men who have sex with men" OR gay OR bisexual OR FSW OR "female sex worker*" OR "sex work*" OR PWID OR "people who inject drugs" OR "injection drug user*" OR IDU OR transgender OR trans OR "gender diverse" OR "key population*") | 65,919 |
| 11 | Key population: search subject | ((MH "men who have sex with men") OR (MH "sex worker") OR (MH "injection drug user") OR (MH transgender)) | 2,948 |
| 12 | | 10 OR 11 | 65,919 |
| 13 | Combined | 3 AND 6 AND 9 AND 12 | 46 |
| 14 | Combined + date limit | 13 limit 01/2005 to 12/2025 | 45 |

| Scopus | | | |
|---|---|---|---|
| **No.** | **Concept** | **Search string** | **Results** |
| 1 | Nigeria | INDEXTERMS (Nigeria*) | 69,786 |
| 2 | | TITLE-ABS-KEY (Nigeria*)) | 151,795 |
| 3 | | 1 OR 2 | 151,795 |
| 4 | Context | TITLE-ABS-KEY (<br>determinant* OR "social determinant*" OR "structural determinant*" OR risk or factor* OR experience* OR vulnerability OR stigma OR discrimination OR poverty OR economic OR criminal* OR law OR legislation OR policy) | 24,935,292 |
| 5 | | INDEXTERMS ("social determinant of health") OR INDEXTERMS ("socioeconomic status") OR INDEXTERMS (stigmatization) OR INDEXTERMS ("health inequality") OR INDEXTERMS (criminalization) OR INDEXTERMS (poverty) OR INDEXTERMS ("health disparity") OR INDEXTERMS (legislation) OR INDEXTERMS ("vulnerable population") | 420,398 |
| 6 | | 4 OR 5 | 24,955,036 |
| 7 | HIV service | TITLE-ABS-KEY (<br>"HIV program*" OR "HIV service*" OR "HIV prevention" OR "HIV treatment" OR "harm reduction" OR PrEP OR PEP OR ART OR "antiretroviral therapy") | 1,476,577 |
| 8 | | INDEXTERMS ("human immunodeficiency virus infection") OR INDEXTERMS ("antiretroviral therapy") OR INDEXTERMS ("preexposure prophylaxis") OR INDEXTERMS ("HIV prevention") OR INDEXTERMS ("harm reduction") | 352,166 |
| 9 | | 7 OR 8 | 1,705,914 |
| 10 | Key population | TITLE-ABS-KEY (<br>MSM OR gbMSM OR "men who have sex with men" OR gay OR bisexual OR FSW OR "female sex worker*" OR "sex work*" OR PWID OR "people who inject drugs" OR "injection drug user*" OR IDU OR transgender OR trans OR "gender diverse" OR "key population*") | 795,410 |

| | | | |
|---|---|---|---|
| 11 | | INDEXTERMS ("men who have sex with men") OR INDEXTERMS ("sex worker") OR INDEXTERMS ("injection drug user") OR INDEXTERMS (transgender) | 36,720 |
| 12 | | 10 OR 11 | 795,410 |
| 13 | | 3 AND 6 AND 9 AND 12 | 273 |
| 14 | | 13<br>AND<br>PUBYEAR > 2004 AND PUBYEAR < 2026 | 251 |

## APPENDIX D: Objective 1, Supplemental Tables

**Table S1.** Unconsolidated descriptions of individual-level determinants associated with HIV service outcomes among key populations in Nigeria, according to HIV care continuum stage, key population group, and geopolitical zone.

| Determinant | Care continuum stage | Finding | Key population(s) | Geopolitical zone(s) | Source |
|---|---|---|---|---|---|
| Age | Prevention | - Older age (22-30 vs. <21) is associated with higher odds of consistent condom and condom/lubricant use | MSM, TG | NC, SW | Crowell (2019) |
| Age | Prevention | - Older age (vs. 16–19) is associated with lower consistent condom use | MSM, TG | NC, SW | Olawore (2021) |
| Age | Prevention | - Older than 35 years (vs. 18-24) is associated with higher odds of PrEP continuation past 6 months | FSW, MSM, PWID, TG | NC, NE, NW, SW, SS | Nwosu (2025) |
| Age | Prevention | - Younger age (16-19 vs. ≥25) is associated with lower odds of having received information about HIV prevention | MSM, TG | NC, SW | Ramadhani (2020) |
| Age | Testing | - Younger age of sexual debut (<16 vs. ≥16) is associated with lower odds of HIV testing | MSM, TG | NC, SW | Volpi (2025) |
| Age | Testing | - Inconsistent age pattern for prenatal testing among FSW | FSW | NC, NE, NW, SW, SS, SE | Olakunde (2024) |
| Age | Testing | - Younger age (<25) is associated with lower rate of visit adherence (not attending expected number of visit in 3 months) | MSM, TG | NC, SW | Kayode (2020) |
| Age | Testing | - Younger age (<25) is associated with higher loss-to-follow-up (not attending scheduled visit in past 180 days) | MSM, TG | NC, SW | Kayode (2020) |
| Age | Testing | - Younger age (16–19 vs. ≥25) is associated with lower odds of HIV testing | MSM, TG | NC, SW | Ramadhani (2020) |
| Age | Testing | - Younger age (<=19, 20-29 vs. ≥30) is associated with lower odds of HIV testing | MSM | NC, SW | Ramadhani (2018) |
| Age | Testing | - Younger age (18-25 vs. 26-40) is associated with increased odds of never having tested for HIV | MSM | NC, SW | Vu (2013) |
| Age | Testing | - Older age (20-24 and 25+ vs. 16-19) at enrollment is associated with higher odds of HIV testing | MSM, TG | NC, SW | Volpi (2025) |
| Age | Treatment | - Younger age at enrollment (<25 and 25-<40 vs. 40–55) is associated with higher risk of ART attrition | FSW, MSM, PWID, TG | NC | Ibiloye (2021) |
| Age | Treatment | - Younger age (20-24 vs. ≥25) is associated with lower odds of ART uptake | MSM, TG | NC, SW | Ramadhani (2020) |
| Age | Treatment | - Age 20–29 (vs. ≥30) is associated with lower odds of ART uptake | MSM | NC, SW | Ramadhani (2018) |

| | | | | | |
|---|---|---|---|---|---|
| Age | Treatment | - Age 20–29 (vs. ≥30) is associated with lower odds of viral suppression - | MSM | NC, SW | Ramadhani (2018) |
| Confidentiality concerns | Testing | - Fear of confidentiality breaches is described as a barrier to HIV self-testing | FSW | SS | Anyiam (2025) |
| Education level | Prevention | - Higher educational level (senior secondary and above vs. junior secondary and less) is associated with higher odds of consistent condom and condom/lubricant use | MSM, TG | NC, SW | Crowell (2019) |
| Education level | Prevention | - Higher educational level (post-secondary vs. none) is associated with higher odds of PrEP continuation past 6mo | FSW, MSM, PWID, TG | NC, NE, NW, SW, SS | Nwosu (2025) |
| Education level | Prevention | - Higher educational level (secondary vs. none, primary) is associated with consistent condom and condom/lubricant use | MSM, TG | NC, SW | Olawore (2021) |
| Education level | Prevention | - Higher educational level (senior secondary and above vs. less than senior secondary) is associated with higher odds of PrEP initiation | MSM, TG | NC, SW | Ramadhani (2019) |
| Education level | Prevention | - Higher educational level (tertiary or vocational vs. none) is associated with consistent condom and condom/lubricant use | MSM | NC | Stromdahl (2012) |
| Education level | Testing | - Education below high school level (vs. above) is associated with lower rate of visit adherence (not attending expected number of visit in 3 months) | MSM, TG | NC, SW | Kayode (2020) |
| Education level | Testing | - Education below high school level (vs. above) is associated with higher loss-to-follow-up (not attending scheduled visit in past 180 days) | MSM, TG | NC, SW | Kayode (2020) |
| Education level | Testing | - Higher educational level (senior secondary and above vs. less than senior secondary) is associated with higher odds of HIV testing | MSM | NC, SW | Ramadhani (2018) |
| Education level | Testing | - Higher education level is associated with prenatal testing (tertiary education vs. none) | FSW | NC, NE, NW, SW, SS, SE | Olakunde (2024) |
| Education level | Testing | - Secondary education or less (vs. tertiary) is associated with increased odds of never having tested for HIV | MSM | NC, SW | Vu (2013) |
| Education level | Testing | - Higher educational level (>senior secondary vs. <=senior secondary) is associated with higher odds of HIV testing | MSM, TG | NC, SW | Volpi (2025) |
| Education level | Treatment | - Quranic education (vs. formal) and no education (vs. formal) is associated with higher risk of ART attrition | FSW, MSM, PWID | NC | Ibiloye (2018) |
| Education level | Treatment | - No education (vs. formal) is associated with lower odds of ART adherence | FSW, MSM, PWID | NC | Ibiloye (2018) |
| Education level | Treatment | - Post-secondary education (vs. none) is associated with lower odds of viral suppression | FSW | NC, NW, SW, SS | Nwosu (2024) |
| Education level | Treatment | - Higher educational level (senior secondary and above vs. less than senior secondary) is associated with higher odds of ART uptake | MSM | NC, SW | Ramadhani (2018) |
| Education level | Treatment | - Higher educational level (>senior secondary vs. <=senior secondary) is associated with higher odds of ART uptake | MSM, TG | NC, SW | Volpi (2025) |
| Employment status | Prevention | - Not employed (vs. employed) is associated with lower odds of PrEP continuation past 6mo | FSW, MSM, PWID, TG | NC, NE, NW, SW, SS | Nwosu (2025) |

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|---|---|---|---|---|---|
| Employment status | Prevention | - Any employment status other than employed is associated with lower PrEP uptake and continuation | FSW, MSM, PWID, TG | NC, NE, NW, SW, SS, SE | Olakunde (2024) |
| Employment status | Testing | - Unemployment (vs. employed) is associated with increased odds of never having tested for HIV | MSM | NC, SW | Vu (2013) |
| Employment status | Treatment | - Unemployment (vs. employed) is associated with higher risk of ART attrition | FSW, MSM, PWID | NC | Ibiloye (2018) |
| Employment status | Treatment | - Student status (vs. employed) is associated with higher odds of viral suppression | FSW | NC, NW, SW, SS | Nwosu (2024) |
| Gender identity | General services | - TG, nonbinary gender identity (vs. cisgender) is associated with higher odds of viral suppression | MSM, TG | NC, SW | Volpi (2025) |
| Gender identity | Prevention | - Non-binary gender identity is associated with lower consistent condom use | MSM, TG | NC, SW | Olawore (2021) |
| Gender identity | Treatment | - Being a trans woman (vs. cisgender man) is associated with higher rate of visit adherence (not attending expected number of visits in 3 months) | MSM, TG | NC, SW | Kayode (2020) |
| HIV status | General services | - HIV negative status (vs. HIV+) is associated with a greater risk of HIV service LTFU | MSM | NC | Schwartz (2015) |
| HIV status | General services | - Not living with HIV (vs. HIV-positive) is associated with greater risk of loss-to-follow-up (not attending scheduled visit in past 180 days) | MSM, TG | NC, SW | Kayode (2020) |
| HIV status | General services | - Not living with HIV (vs. HIV-positive) is associated with lower rate of visit adherence (not attending expected number of visits in 3 months) | MSM, TG | NC, SW | Kayode (2020) |
| HIV status | Prevention | - Known HIV-positive status (vs. negative, unknown) is associated with consistent condom/lubricant use | MSM, TG | NC, SW | Crowell (2019) |
| HIV status | Prevention | - Unknown HIV diagnosis (vs. HIV-negative) is associated with lower odds of consistent condom use | MSM, TG | NC, SW | Crowell (2019) |
| HIV status | Prevention | - Known HIV-positive status (vs. negative, unknown) is associated with consistent condom use | MSM, TG | NC, SW | Olawore (2021) |
| HIV status | Prevention | - Unknown HIV status (vs. HIV-negative) is associated with lower consistent condom use | MSM, TG | NC, SW | Olawore (2021) |
| HIV status | Testing | - HIV-negative status (vs. positive) is associated with increased odds of never having tested for HIV | MSM | NC, SW | Vu (2013) |
| HIV test history | General services | - No prior HIV testing history (vs. ever tested) is associated with greater risk of HIV service LTFU | MSM | NC | Schwartz (2015) |
| HIV test history | General services | - No prior HIV testing history (vs. ever tested) is associated with lower rate of visit adherence (not attending expected number of visits in 3 months) | MSM, TG | NC, SW | Kayode (2020) |
| HIV test history | Prevention | - Prior HIV testing history (ever tested) is associated with higher odds of consistent condom use | MSM | NC | Stromdahl (2012) |
| HIV test history | Prevention | - Prior HIV testing history (ever tested) is associated with consistent condom use | MSM, TG | NC, SW | Olawore (2021) |

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|---|---|---|---|---|---|
| HIV test history | Testing | - Ever tested for HIV (vs. never tested) is associated with higher odds of HIV testing | MSM | NC, SW | Ramadhani (2018) |
| HIV/STI knowledge | Prevention | - Knowledge that HIV can be transmitted through anal sex is associated with higher odds of consistent condom use | MSM | NC | Stromdahl (2012) |
| HIV/STI knowledge | Prevention | - Knowledge that STIs can be transmitted through anal sex is associated with higher odds of consistent condom use | MSM | NC | Stromdahl (2012) |
| HIV/STI knowledge | Prevention | - Knowledge that anal sex carries the highest HIV risk, is associated with consistent condom and condom/lubricant use | MSM, TG | NC, SW | Olawore (2021) |
| HIV/STI knowledge | Prevention | - PrEP awareness (vs. unaware) is associated with PrEP uptake | MSM, TG | NC, SW | Ogunbajo (2019) |
| HIV/STI knowledge | Testing | - Receipt of HIV prevention information in the past year are associated with HIV testing uptake | MSM | NC, SW | Ramadhani (2018) |
| HIV/STI knowledge | Testing | - Exposure to HIV health information (vs. not) in the past year is associated with higher odds of HIV testing uptake | MSM, TG | NC, SW | Volpi (2025) |
| HIV/STI knowledge | Treatment | - Low awareness of the community ART programme is described as a barrier to ART adherence | FSW, MSM, PWID | NC | Ibiloye (2024) |
| HIV/STI knowledge | Treatment | - Exposure to HIV health information in the past year is associated with higher odds of viral suppression | MSM, TG | NC, SW | Volpi (2025) |
| HIV/STI knowledge | Treatment | - Exposure to HIV health information in the past year is associated with lower odds of ART uptake | MSM, TG | NC, SW | Volpi (2025) |
| Internet use | General services | - Not having a cell phone (vs. having one) is associated with higher risk of loss-to-follow-up (not attending scheduled visit in past 180 days) | MSM, TG | NC, SW | Kayode (2020) |
| Internet use | General services | - Not having a cell phone (vs. having one) is associated with lower rate of visit adherence (not attending expected number of visits in 3 months) | MSM, TG | NC, SW | Kayode (2020) |
| Internet use | Prevention | - Daily internet use (vs. never) is associated with higher odds of consistent condom and condom/lubricant use | MSM, TG | NC, SW | Crowell (2019) |
| Key population | Prevention | - PWID, MSM, and TG individuals (vs. FSW) have lower odds of PrEP continuation past 6 months | FSW, MSM, PWID, TG | NC, NE, NW, SW, SS | Nwosu (2025) |
| Key population | Prevention | - MSM and TG people have higher PrEP uptake than FSW | FSW, MSM, PWID, TG | NC, NE, NW, SW, SS, SE | Olakunde (2024) |
| Key population | Prevention | - Key population group predicts timing of PrEP continuation differently (PWID and FSW higher at 0–3 months, MSM higher at 4–12 months) | FSW, MSM, PWID | NC, NW, SW, SS | Ochonye (2024) |
| Key population | Treatment | - MSM key population group (vs. FSW) is associated with higher risk of ART attrition | FSW, MSM, PWID, TG | NC | Ibiloye (2021) |
| Marital status | Prevention | - Divorced, widowed, separated status (vs. single) is associated with higher odds of consistent condom use | MSM, TG | NC, SW | Crowell (2019) |
| Marital status | Prevention | - Single or formerly married (vs. currently married) is associated with higher PrEP uptake | FSW, MSM, PWID, TG | NC, NE, NW, SW, SS, SE | Olakunde (2024) |

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|---|---|---|---|---|---|
| Marital status | Prevention | - Marital status is significantly associated with PrEP use (higher proportion of single people used prep vs. married) | FSW | NW | Sadiq (2025) |
| Marital status | Testing | - Married marital status is associated with the highest prenatal HIV testing uptake | FSW | NC, NE, NW, SW, SS, SE | Olakunde (2024) |
| Personal beliefs | Treatment | - Desire for health is described as a facilitator to ART adherence | FSW, MSM | NC, SW | Dirisu (2024) |
| Personal beliefs | General services | - Wanting to know and confirm HIV status is described as a facilitator to HIV service uptake among 91% of participants | FSW, MSM, PWID | NW | Emmanuel (2025) |
| Personal beliefs | General services | - Wanting to know more about HIV is described as a facilitator to HIV service uptake among 3% of participants | FSW, MSM, PWID | NW | Emmanuel (2025) |
| Personal beliefs | General services | - Seeking precaution, protection is described as a facilitator to ART access among 6% of participants | FSW, MSM, PWID | NW | Emmanuel (2025) |
| Personal beliefs | Prevention | - Being very worried about HIV is associated with lower consistent condom use | MSM, TG | NC, SW | Olawore (2021) |
| Personal beliefs | Testing | - Perceived test inaccuracy is described as a barrier to HIV self-testing | FSW | SS | Anyiam (2025) |
| Personal beliefs | Testing | - Anxiety of conducting a test alone is described as a barrier to HIV self-testing | FSW | SS | Anyiam (2025) |
| Personal beliefs | Treatment | - Low motivation to adhere is described as a barrier to ART adherence | FSW, MSM | NC, SW | Dirisu (2024) |
| Programme history | Treatment | - Engagement in TasP programme (vs. did not engage) is associated with lower odds of loss-to-follow-up (not having visit within three months of last visit) | MSM | NC | Charurat (2015) |
| Personal health | Treatment | - A higher baseline BMI (30+ vs. 18.5-24.9) is associated with higher odds of viral suppression | FSW | NC, NW, SW, SS | Nwosu (2024) |
| Personal health | Treatment | -An EFV-based (vs. DTG-based) ART regimen is associated with lower odds of viral suppression | FSW | NC, NW, SW, SS | Nwosu (2024) |
| Personal health | Treatment | - A higher WHO baseline clinical stage (3&4 vs. 1) is associated with lower odds of viral suppression | FSW | NC, NW, SW, SS | Nwosu (2024) |
| Personal health | Treatment | - Minimal adverse effects of ART (93.1%) among those taking ART | FSW, MSM, PWID, TG | SW | Okonkwo (2024) |
| Programme history | Prevention | - Longer time since programme enrollment (15 and 9 months vs. at enrollment) is associated with higher odds of consistent condom use | MSM, TG | NC, SW | Crowell (2019) |
| Programme history | Prevention | - Prior STI testing (past 12 months) and current STI treatment are associated with consistent condom use and PrEP uptake | MSM, TG | NC, SW | Olawore (2021) |
| Programme history | Prevention | - Prior prevention session engagement (vs. not) is associated with higher odds of PrEP initiation | MSM, TG | NC, SW | Ramadhani (2023) |

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| Programme history | Prevention | - Having a PrEP assessment once medication became available is associated with higher odds of PrEP initiation - MSM and TG people, North-Central and South-West zones (Ramadhani 2019) | MSM, TG | NC, SW | Ramadhani (2023) |
| Programme history | Prevention | - Having a PrEP assessment once medication became available is associated with lower odds of PrEP adherence | MSM, TG | NC, SW | Ramadhani (2023) |
| Programme history | Prevention | - Participation in HIV prevention meetings (vs. not) is associated with lower odds of PrEP adherence | MSM, TG | NC, SW | Ramadhani (2023) |
| Programme history | Prevention | - Having participated in a prevention session in the past 12mo is associated with PrEP uptake | FSW | NW | Sadiq (2025) |
| Programme history | Prevention | - History of using drugs to treat STI associated with PrEP use (higher percentage of those who had, used prep) | FSW | NW | Sadiq (2025) |
| Programme history | Testing | - Prior participation in HIV prevention meetings is associated with higher odds of HIV testing | MSM | NC, SW | Ramadhani (2018) |
| Programme history | Treatment | - Later year of ART initiation (2017-2022 vs. 2016) is associated with higher odds of viral suppression | FSW | NW, SS | Nwosu (2024) |
| Religion | Prevention | - Religion other than Christianity (vs. Christian) is associated with lower PrEP uptake and continuation | FSW, MSM, PWID, TG | NC, NE, NW, SW, SS, SE | Olakunde (2024) |
| Religion | Prevention | - Religion is significantly associated with PrEP use (higher proportion Christian used PrEP vs. Islam) | FSW | NW | Sadiq (2025) |
| Religion | Treatment | - Muslim and other religion (vs. Christian) is associated with lower ART uptake (TasP) | MSM | NC | Charurat (2015) |
| Religion | Treatment | - Muslim and other religion (vs. Christian) are associated with higher odds of viral suppression | MSM | NC, SW | Ramadhani (2018) |
| Religion | Treatment | - Muslim religion (vs. Christian) is associated with lower odds of ART uptake | MSM | NC, SW | Ramadhani (2018) |
| Safety and comfort | Treatment | - Never having been afraid to access health services (vs. having been afraid) is associated with lower rate of visit adherence | MSM, TG | NC, SW | Kayode (2020) |
| Safety and comfort | Treatment | - Never having been afraid to access health services (vs. having been afraid) is associated with higher risk of loss-to-follow-up (not attending scheduled visit in past 180 days) | MSM, TG | NC, SW | Kayode (2020) |
| SES | General services | - Financial limitations (9.1%) as challenge to accessing ART | FSW, MSM, PWID, TG | NC, SW | Okonkwo (2024) |
| SES | Treatment | - Financial difficulty (vs. not) is associated with lower odds of ART appointment-keeping | MSM | NC | Afolaranmi (2021) |
| SES | Treatment | - Work schedule conflicts are described as a barrier to ART adherence | FSW, MSM | NC, SW | Dirisu (2024) |
| SES | Treatment | - Socioeconomic factors (transport fare, competing priorities such as food) are described as barriers to ART adherence | FSW, MSM | NC, SW | Dirisu (2024) |

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| Sex | Prevention | - Male sex (vs. female) has lower odds of PrEP continuation past 6 months | FSW, MSM, PWID, TG | NC, NE, NW, SW, SS | Nwosu (2025) |
| Sex | Treatment | - Male sex (vs. female) is associated with higher risk of ART attrition | FSW, MSM, PWID, TG | NC | Ibiloye (2021) |
| Sex work dynamics | Treatment | - Exchange of sex in the past year (vs. did not) is associated with lower ART uptake | MSM, TG | NC, SW | Volpi (2025) |
| Sexual orientation | General services | - Bisexual or other sexual orientation (vs. homosexual) is associated with higher odds of ART uptake | MSM, TG | NC, SW | Volpi (2025) |
| Sexual orientation | Testing | - Bisexual sexual orientation (vs. homosexual) is associated with lower rate of visit adherence (not attending expected number of visits in 3 months) | MSM, TG | NC, SW | Kayode (2020) |
| Sexual orientation | Testing | - Homosexual orientation (vs. bisexual) is associated with higher odds of HIV testing | MSM | NC, SW | Ramadhani (2018) |
| Sexual orientation | Treatment | - Bisexual or other orientation (vs. homosexual) is associated with lower odds of HIV testing | MSM, TG | NC, SW | Volpi (2025) |
| Sexual practices | General services | - Insertive anal sex in the past year (vs. receptive only) and selling sex in the past year are associated with higher loss-to-follow-up (not attending scheduled visit in past 180 days) | MSM, TG | NC, SW | Kayode (2020) |
| Sexual practices | General services | - Lifetime history of forced sex is associated with higher odds of HIV testing | MSM, TG | NC, SW | Volpi (2025) |
| Sexual practices | General services | - More receptive sex partners in the past year (3+ vs. 0-2) is associated lower odds of HIV testing | MSM, TG | NC, SW | Volpi (2025) |
| Sexual practices | General services | - Not using a condom at last sex is associated with increased odds of never having tested for HIV | MSM | NC, SW | Vu (2013) |
| Sexual practices | General services | - Exchanged sex in the past year (vs. did not) is associated with lower odds of viral suppression | MSM, TG | NC, SW | Volpi (2025) |
| Sexual practices | Prevention | - Receiving money for casual sex with a man is associated with lower odds of consistent condom use | MSM | NC | Stromdahl (2012) |
| Sexual practices | Prevention | - Buying condoms or obtaining through other means (vs. receiving free) is associated with lower consistent condom use | MSM, TG | NC, SW | Olawore (2021) |
| Sexual practices | Prevention | - Higher insertive anal sex frequency (6+ vs. 0 acts in past 30 days) is associated with PrEP uptake | MSM | NC, SW, SS | Ogunbajo (2019) |
| Sexual practices | Prevention | - Willingness to engage in unprotected sex given incentives (vs. not) is associated with lower PrEP uptake | FSW | SS | Omo-Emmanuel (2023) |
| Sexual practices | Testing | - Sex work during pregnancy is associated with lower prenatal HIV testing uptake | FSW | NC, NE, NW, SW, SS, SE | Olakunde (2024) |
| Sexual practices | Testing | - Inconsistent condom use is associated with lower prenatal HIV testing uptake | FSW | NC, NE, NW, SW, SS, SE | Olakunde (2024) |

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| Sexual practices | Testing | - Consistent condom use (vs. not) is associated with higher prenatal HIV testing uptake | FSW | NC, NE, NW, SW, SS, SE | Olakunde (2024) |
| Sexual practices | Testing | - Abstaining from sex work during pregnancy is associated with higher prenatal HIV testing uptake | FSW | NC, NE, NW, SW, SS, SE | Olakunde (2024) |
| Sexual practices | Testing | - Insertive anal sex in the past year (vs. receptive only) is associated with lower rate of visit adherence (not attending expected number of visits in 3 months) | MSM, TG | NC, SW | Kayode (2020) |
| Sexual practices | Testing | - Selling sex in the past year is associated with lower rate of visit adherence (not attending expected number of visits in 3 months) | MSM, TG | NC, SW | Kayode (2020) |
| Sexual practices | Testing | - Selling sex in the past year are associated with higher risk of LTFU | MSM, TG | NC, SW | Kayode (2020) |
| Sexual practices | Treatment | - Lifetime history of condomless anal sex (vs. not) is associated with higher odds of HIV testing | MSM, TG | NC, SW | Volpi (2025) |
| Stigma | General services | - Anticipatory stigma is described as discouraging clients from going to healthcare facility | MSM | SW | Ogunbajo (2025) |
| Stigma | Treatment | - Internalised stigma id described as a personal motivator to achieve undetectable viral load (U=U) | MSM | SW | Ogunbajo (2025) |
| Stigma | Treatment | - Stigma that leads to depression is described as a barrier to remaining ART adherent | MSM | SW | Ogunbajo (2025) |

**Table S2.** Unconsolidated descriptions of network-level determinants associated with HIV service outcomes among key populations in Nigeria, according to HIV care continuum stage, key population group, and geopolitical zone.

| Determinant | Care continuum stage | Finding | Key population(s) | Geopolitical zone(s) | Source |
|---|---|---|---|---|---|
| Disclosure to family, partners | Prevention | - Partner non-disclosure of HIV status is reported among 0.5% of participants initiating PrEP | FSW, MSM, PWID | NC, NW, SS | Ochonye (2024) |
| Disclosure to family, partners | Testing | - MSM disclosure to family is associated with higher odds of HIV testing | MSM | NC, SW | Ramadhani (2018) |
| Disclosure to family, partners | Testing | - MSM disclosure to family is associated with higher odds of HIV testing | MSM, TG | NC, SW | Volpi (2025) |
| Disclosure to family, partners | Treatment | - Awareness of a regular male partner's HIV status facilitated consistent ART appointment-keeping over 6 months | MSM | NC | Afolaranmi (2021) |
| Disclosure to family, partners | Treatment | - Disclosure of MSM status to family is associated with ART uptake (TasP) | MSM | NC | Charurat (2015) |
| Disclosure to family, partners | Treatment | - HIV status disclosure to family is described as a facilitator of ART adherence and retention | FSW, MSM | NC, SW | Dirisu (2024) |
| Education level | Treatment | - Partner SES (the same vs. lower) is associated with higher odds of ART uptake | MSM | NC, SW | Ramadhani (2018) |
| Education level | Treatment | - Partner SES (same vs. lower) is associated with higher odds of viral suppression | MSM | NC, SW | Ramadhani (2018) |
| HIV, STBBI knowledge | Treatment | - Awareness of a fellow MSM dying after discontinuing ART facilitated consistent ART appointment-keeping over 6 months | MSM | NC | Afolaranmi (2021) |
| Network size, density | Prevention | - Higher network density (≥50% vs. <50%) is associated with higher odds of PrEP uptake | MSM, TG | NC, SW | Ramadhani (2019) |
| Network size, density | Testing | - All network sizes larger than 1–10 are associated with HIV testing uptake | MSM | NC, SW | Ramadhani (2018) |
| Network size, density | Testing | - Network size 11-20 (vs. 1-10) is associated with reduced odds of ART uptake | MSM | NC, SW | Ramadhani (2018) |
| Network size, density | Treatment | - Larger network size x higher social support (vs. small network size x social support) is associated with higher odds of ART uptake | MSM | NC, SW | Ramadhani (2018) |

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|---|---|---|---|---|---|
| Network size, density | Treatment | - Larger network size x higher social support (vs. small network size x social support) is associated with higher odds of viral suppression | MSM | NC, SW | Ramadhani (2018) |
| Partner dynamics | Prevention | - Inability to negotiate condom use is reported among 0.4% participants initiating PrEP | FSW, MSM, PWID | NC, NW, SS | Ochonye (2024) |
| Partner dynamics | Prevention | - Partner unwillingness to undergo HIV testing is reported among <1% of participants initiating PrEP | FSW, MSM, PWID | NC, NW, SS | Ochonye (2024) |
| Partner dynamics | Prevention | - Sero-discordant relationship is reported among 10% of participants initiating PrEP | FSW, MSM, PWID | NC, NW, SS | Ochonye (2024) |
| SES | Treatment | - Partner education level (>senior secondary) is associated with higher odds of ART uptake | MSM | NC, SW | Ramadhani (2018) |
| SES | Treatment | - Partner education level (>senior secondary) is associated with higher odds of HIV testing | MSM | NC, SW | Ramadhani (2018) |
| Sex work dynamics | Prevention | - Greater client load per day and non-gatekeeper control of work are associated with higher odds of PrEP uptake | FSW | NW | Sadiq (2025) |
| Social support | Prevention | - Higher social support is associated with higher odds of PrEP uptake | MSM, TG | NC, SW | Ramadhani (2019) |
| Social support | General services | - Having friends who are MSM, and heterosexual (vs. not) is associated with higher rate of visit adherence | MSM, TG | NC, SW | Kayode (2020) |
| Social support | General services | - Trusting the majority of MSM they know (vs. not) is associated with lower rate of visit adherence | MSM, TG | NC, SW | Kayode (2020) |
| Social support | General services | - Trusting the majority of MSM they know (vs. not) is associated with higher risk of LTFU | MSM, TG | NC, SW | Kayode (2020) |
| Social support | Testing | - Higher social support is associated with higher odds of HIV testing uptake | MSM | NC, SW | Ramadhani (2018) |
| Social support | Treatment | - Family, spousal support is described as a facilitator to ART adherence and retention | FSW, MSM | NC, SW | Dirisu (2024) |
| Social support | Treatment | - Higher social support is associated with higher odds of ART uptake | MSM | NC, SW | Ramadhani (2018) |
| Social support | Treatment | - Higher social support is associated with higher odds of viral suppression | MSM | NC, SW | Ramadhani (2018) |

**Table S3.** Unconsolidated descriptions of community-level determinants associated with HIV service outcomes among key populations in Nigeria, according to HIV care continuum stage, key population group, and geopolitical zone.

| Determinant | Care continuum stage | Findings | Key population(s) | Geopolitical zone | Source |
|---|---|---|---|---|---|
| Age | General services | - Younger age 16-19 vs. ≥25) is associated with decreased odds of disclosing MSM status to healthcare provider | MSM, TG | NC, SW | Ramadhani (2020) |
| Confidentiality concerns | Prevention | - Higher satisfaction with provider confidentiality at peer-led (vs. public sector) facilities is associated with access to HIV services | FSW, MSM, PWID | NC, SE, SS | Ochonye (2019) |
| Confidentiality concerns | Prevention | - Confidentiality concerns are more frequently identified as a barrier to accessing HIV services at public sector (10%) compared to peer-led facilities (3%) | FSW, MSM, PWID | NC, SE, SS | Ochonye (2019) |
| Confidentiality concerns | Prevention | - Confidentiality concerns are most frequently identified by PWID (19%) at public facility, and among MSM (4%) at peer facility | FSW, MSM, PWID | NC, SE, SS | Ochonye (2019) |
| Confidentiality concerns | Testing | - Fear of confidentiality breach at public facilities is associated with lower HIV testing uptake | MSM, TG | NC, SW | Rodriguez-Hart (2018) |
| Confidentiality concerns | Treatment | - Lack of confidentiality around HIV status and sexuality at general healthcare facilities is described as a barrier to HIV service access | MSM | NC, SW | Balogun (2020) |
| Confidentiality concerns | Treatment | - Separation and labelling of HIV wards (risking identity disclosure) is described as a barrier to HIV service access | MSM | NC, SW | Balogun (2020) |
| Confidentiality concerns | Treatment | - Confidentiality and privacy maintained at the facility are described as facilitators to ART retention | FSW, MSM, PWID | NC | Ibiloye (2024) |
| Confidentiality concerns | Treatment | - Confidentiality and privacy are described as being important to the OSS facility by 95% of participants | FSW, MSM, PWID, TG | SW | Okonkwo (2024) |
| Disclosure to providers | Prevention | - MSM status disclosure to a healthcare worker is associated with consistent condom use | MSM, TG | NC, SW | Olawore (2021) |
| Disclosure to providers | General services | - Non-disclosure of MSM status to healthcare provider is associated with lower rate of visit adherence | MSM, TG | NC, SW | Kayode (2020) |
| Disclosure to providers | General services | - Non-disclosure of MSM status to healthcare provider is associated with higher risk of LTFU | MSM, TG | NC, SW | Kayode (2020) |
| Disclosure to providers | General services | - Anticipated stigma in gender identity disclosure is described as a barrier to HIV services | TG | SW | Tun (2022) |
| Disclosure to providers | Testing | - MSM status disclosure to a healthcare worker is associated with higher odds of HIV testing | MSM | NC, SW | Ramadhani (2018) |
| Disclosure to providers | Treatment | - MSM status disclosure to a healthcare worker is associated with ART uptake (TasP) | MSM | NC | Charurat (2015) |

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|---|---|---|---|---|---|
| Disclosure to providers | Treatment | - Non-disclosure of HIV status is described as a barrier to ART retention | FSW, MSM, PWID | NC | Ibiloye (2024) |
| Disclosure to providers | Treatment | - MSM status disclosure to a healthcare worker is associated with higher odds of viral suppression | MSM | NC, SW | Ramadhani (2018) |
| Disclosure to providers | Treatment | - Higher percentage of ART use observed among MSM who disclosed their MSM status to a healthcare provider | MSM | NC | Schwartz (2015) |
| Disclosure to providers | Treatment | - Higher percentage of viral suppression observed among MSM who disclosed their MSM status to a healthcare provider | MSM | NC | Schwartz (2015) |
| Geographical access | General services | - Confidentiality via greater distance to a general healthcare facility is described as a facilitator to HIV service access | MSM | NC, SW | Balogun (2020) |
| Geographical access | General services | - Lagos (vs. Abuja) is associated with higher rate of visit adherence | MSM, TG | NC, SW | Kayode (2020) |
| Geographical access | Prevention | - Lagos (vs. Abuja) is associated with higher consistent condom/lubricant use | MSM, TG | NC, SW | Crowell (2019) |
| Geographical access | Prevention | - Lagos (vs. Abuja) is associated with higher consistent condom use | MSM, TG | NC, SW | Olawore (2021) |
| Geographical access | Testing | - South-South zone has lowest prenatal HIV testing uptake among FSW compared to all other zones | FSW | NC, NW, NE, SE, SW, SS | Olakunde (2024) |
| Geographical access | Testing | - Ibadan and Lagos (vs. Abuja) are associated with lower odds of HIV testing uptake | MSM | NC, SW | Vu (2013) |
| Geographical access | Treatment | - Distance to general health facility and transportation challenges are described as barriers to HIV service access | MSM | NC, SW | Balogun (2020) |
| Geographical access | Treatment | - Uneven geographical availability of specialist facilities by state is described as a barrier to HIV service access | MSM | NC, SW | Balogun (2020) |
| Geographical access | Treatment | - Distance to health facility is described as barrier to ART adherence | FSW, MSM | NC, SW | Dirisu (2024) |
| Geographical access | Treatment | - Rural residence (vs. semi-urban) and urban residence (vs. semi-urban) is associated with higher risk of ART attrition | FSW, MSM, PWID, TG | NC | Ibiloye (2021) |
| Geographical access | Treatment | - Proximity to service delivery point is described as a facilitator to ART retention | FSW, MSM, PWID | NC | Ibiloye (2024) |
| Geographical access | Treatment | - Distance to facility and transport money is described as a barrier to ART retention | FSW, MSM, PWID | NC | Ibiloye (2024) |
| Geographical access | Treatment | -Distance to service is most frequently identified among PWID (20%) (vs. FSW, MSM) as barrier to accessing HIV service at peer-led facility | FSW, MSM, PWID | NC, SE, SS | Ochonye (2019) |
| Geographical access | Treatment | - Distance barriers are described among 22% of participants as a barrier to ART adherence | FSW, MSM, PWID, TG | SW | Okonkwo (2024) |
| Geographical access | Treatment | - Transportation challenges are described among 11% of participants as a barrier to ART adherence | FSW, MSM, PWID, TG | SW | Okonkwo (2024) |

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| Geographical access | Treatment | - Abuja (vs. Lagos) is associated with higher odds of ART uptake | MSM | NC, SW | Ramadhani (2018) |
| Location typology | Testing | - Non-brothel-based FSW typology (vs. brothel-based) is associated with lower prenatal HIV testing uptake | FSW | NC, NW, NE, SE, SW, SS | Olakunde (2024) |
| Peer support | Treatment | - Peer support through support group meetings, opportunities to socialize, and healthcare workers who are key population members are described as a facilitator to ART retention | FSW, MSM, PWID | NC | Ibiloye (2024) |
| Programme delivery | Prevention | - Large patient volumes at public hospitals are described as barrier to HIV prevention service access | MSM | NW, SS | Emmanuel (2019) |
| Programme delivery | Prevention | - Hours of operation at public hospitals are described as barriers to HIV prevention service access | MSM | NW, SS | Emmanuel (2019) |
| Programme delivery | Prevention | - Hasty review of patients by physicians at public hospitals is described as a barrier to HIV prevention service access | MSM | NW, SS | Emmanuel (2019) |
| Programme delivery | Prevention | - Waiting times are more frequently reported as a barrier to HIV prevention service access at public vs. peer facilities (16% vs. 5%) | FSW, MSM, PWID | NC, SE, SS | Ochonye (2019) |
| Programme delivery | Prevention | - Hours of operation are more frequently reported as a barrier to HIV prevention service access at public vs. peer facilities (7% vs. 5%) | FSW, MSM, PWID | NC, SE, SS | Ochonye (2019) |
| Programme delivery | General services | - Lack of free, accessible, and comprehensive services are identified among 24% of participants as a barrier to HIV service access | FSW, MSM, PWID | NW | Emmanuel (2025) |
| Programme delivery | General services | - Lack of key population-friendly facilities is described among 11% of participants as a barrier to HIV service access | FSW, MSM, PWID | NW | Emmanuel (2025) |
| Programme delivery | General services | - Lack of key population-specific information is described among 11% of participants as a barrier to HIV service access | FSW, MSM, PWID | NW | Emmanuel (2025) |
| Programme delivery | General services | - Non-availability of HIV service providers is described among 6% of participants as a barrier to HIV service access | FSW, MSM, PWID | NW | Emmanuel (2025) |
| Programme delivery | General services | - Inability to provide adequate HIV care is described among 6% of participants as a barrier to HIV service access - | FSW, MSM, PWID | NW | Emmanuel (2025) |
| Programme delivery | Testing | - Mobile outreach with a dedicated HIV counselling and testing team and MPPI delivery was associated with highest HIV testing uptake (vs. mobile outreach, mobile outreach + HIV counselling and testing team) | MSM, PWID | NC, NW, SW | Adebajo (2015) |
| Programme delivery | Testing | - Insufficient psychosocial services at community facilities is described as a barrier to HIV testing uptake | MSM, TG | NC, SW | Rodriguez-Hart (2018) |
| Programme delivery | Testing | -HIVST programme design: Phone hotline set up by counsellor to provide information, counselling, referrals to care and treatment | MSM | SW | Tun (2018) |
| Programme delivery | Treatment | - Lack of specialist skills among the healthcare workforce is described as a barrier to HIV service access | MSM | NC, SW | Balogun (2020) |
| Programme delivery | Treatment | - Hostile and unwelcoming staff (particularly toward low-SES clients) is described as a barrier to HIV service access | MSM | NC, SW | Balogun (2020) |

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| Programme delivery | Treatment | - Overcrowding and long wait times at general facilities is described as a barrier to HIV service access | MSM | NC, SW | Balogun (2020) |
| Programme delivery | Treatment | - Quality of adherence counselling is described as a facilitator of ART adherence | FSW, MSM | NC, SW | Dirisu (2024) |
| Programme delivery | Treatment | - Tracking and follow-up are described as facilitators of ART adherence | FSW, MSM | NC, SW | Dirisu (2024) |
| Programme delivery | Treatment | - Community-led ART refill (vs. general clinic) is described as a facilitator to ART adherence | FSW, MSM | NC, SW | Dirisu (2024) |
| Programme delivery | Treatment | - Poor provider attitude is described as a barrier to ART adherence | FSW, MSM | NC, SW | Dirisu (2024) |
| Programme delivery | Treatment | - Logistical supports (short wait times, low patient load, appointment reminders) is described as a facilitator to ART retention | FSW, MSM, PWID | NC | Ibiloye (2024) |
| Programme delivery | Treatment | - Comprehensive and quality care is described as a facilitator to ART retention | FSW, MSM, PWID | NC | Ibiloye (2024) |
| Programme delivery | Treatment | - Provision of incentives (condoms, lubricants, transport reimbursement) are described as a facilitator to ART retention | FSW, MSM, PWID | NC | Ibiloye (2024) |
| Programme delivery | Treatment | - Wrap-around services (STI screening, drugs for other illnesses, cervical cancer screening) are described as facilitators of ART retention | FSW, MSM, PWID | NC | Ibiloye (2024) |
| Programme delivery | Treatment | - Drug refill by proxy is described as facilitators of ART retention | FSW, MSM, PWID | NC | Ibiloye (2024) |
| Programme delivery | Treatment | - Receiving ART in a shared model with other key population groups (risk of accidental disclosure) is described as a barrier to ART retention | FSW, MSM, PWID | NC | Ibiloye (2024) |
| Programme delivery | Treatment | - Non-key population healthcare workers are described as a barrier to ART retention | FSW, MSM, PWID | NC | Ibiloye (2024) |
| Programme delivery | Treatment | - No reserved smoking area is described as a barrier to ART retention | FSW, MSM, PWID | NC | Ibiloye (2024) |
| Safety and comfort | Prevention | - Staff attitude at public hospitals is described as a barrier to HIV prevention service access | MSM | NW, SS | Emmanuel (2019) |
| Safety and comfort | Prevention | - Staff attitudes are more frequently reported as a barrier to HIV prevention service access at public vs. peer facilities (14% vs. 5%) | FSW, MSM, PWID | NC, SE, SS | Ochonye (2019) |
| Safety and comfort | Testing | - Receiving non-health HIV care at community facility is described as a facilitator to HIV testing uptake | MSM, TG | NC, SW | Rodriguez-Hart (2018) |
| Safety and comfort | Testing | -Peer-led (staff are MSM) at community facility are described as a facilitator to HIV testing uptake | MSM, TG | NC, SW | Rodriguez-Hart (2018) |
| Safety and comfort | Testing | -Peer patronage (referral) at community facility is described as a facilitator to HIV testing uptake | MSM, TG | NC, SW | Rodriguez-Hart (2018) |
| Safety and comfort | Testing | - Pride and empowerment in becoming peer educator at community facilitator is described as facilitator to HIV testing uptake | MSM, TG | NC, SW | Rodriguez-Hart (2018) |

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| Safety and comfort | Testing | - Feeling safe and belonging at community facility is described as a facilitator to HIV testing uptake | MSM, TG | NC, SW | Rodriguez-Hart (2018) |
| Safety and comfort | Testing | -Feeling comfortable talking to doctor at community facility is described as a facilitator to HIV testing uptake | MSM, TG | NC, SW | Rodriguez-Hart (2018) |
| Safety and comfort | Testing | - Fear of healthcare provider learning MSM status (anticipated stigma) at public facilities is described as a barrier to HIV testing | MSM, TG | NC, SW | Rodriguez-Hart (2018) |
| Safety and comfort | Testing | - Stigma reducing likelihood of MSM disclosure at public facilities (limiting opportunities for targeted interventions) is associated with lower HIV testing uptake | MSM, TG | NC, SW | Rodriguez-Hart (2018) |
| Safety and comfort | Treatment | - Comfort discussing health concerns with healthcare providers at OSS facility offering ART is reported by 93% of participants | FSW, MSM, PWID, TG | SW | Okonkwo (2024) |
| Safety and comfort | Treatment | - Conducive clinic environment at an OSS facility is described by 94% of participants | FSW, MSM, PWID, TG | SW | Okonkwo (2024) |
| Safety and comfort | Treatment | - Encouraging staff attitudes are described by 97% of participants at OSS facilities | FSW, MSM, PWID, TG | SW | Okonkwo (2024) |
| Service accessibility | Testing | - Access to antenatal care is associated with prenatal HIV testing uptake | FSW | NC, NW, NE, SE, SW, SS | Olakunde (2024) |
| Service accessibility | Treatment | - Limited availability and accessibility of key population-friendly clinics is described as a barrier to HIV service access | MSM | NC, SW | Balogun (2020) |
| Service affordability | Prevention | - Out-of-pocket expenses at private hospitals is described as a barrier to HIV prevention service access | MSM | NW, SS | Emmanuel (2019) |
| Service affordability | Treatment | - ART and diagnostic fees at general facilities (despite supposed universal free access) are described as barrier to HIV service access | MSM | NC, SW | Balogun (2020) |
| Service affordability | Treatment | - Cost of services is most frequently identified among PWID (9%) (vs. FSW, MSM) as barrier to accessing HIV service at peer-led facility | FSW, MSM, PWID | NC, SE, SS | Ochonye (2019) |
| Service affordability | Treatment | - Cost of services is most frequently identified as a barrier to HIV prevention service access at public vs. peer led facilities (9% vs. 3%) | FSW, MSM, PWID | NC, SE, SS | Ochonye (2019) |
| Social support | Treatment | - Peer support via group meetings, recreational facilities, opportunities to socialize is described as a facilitator to ART adherence and retention | FSW, MSM, PWID | NC | Ibiloye (2024) |
| Stigma | General services | - Disrespect and misgendering by healthcare providers is described as a barrier to HIV service access | TG | SW | Tun (2022) |
| Stigma | General services | - Experiencing stigma or refusal of service by healthcare providers on the basis of gender identity is described as a barrier to HIV service access | TG | SW | Tun (2022) |
| Stigma | Treatment | - Stigmatising and discriminatory responses from providers regarding sexual practices at general healthcare facilities is described as a barrier to HIV service access | MSM | NC, SW | Balogun (2020) |
| Stigma | Treatment | - General stigma is described as a barrier to ART adherence | FSW, MSM | NC, SW | Dirisu (2024) |

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| Stigma | Treatment | - Intra-facility stigma and discrimination (towards MSM in particular vs. PWID, FSW), is described as a barrier to ART retention | FSW, MSM, PWID | NC | Ibiloye (2024) |

## APPENDIX E: Objective 2, Supplemental Tables

**Table S4.** Sociodemographic, behavioural, and virologic characteristics of key populations; Nigerian IBBSS (2020).

| | | HIV Ab-negative (N=15,096) | HIV Ab-positive (N=2,279) | | |
|---|---|---|---|---|---|
| | | | Non-viremic (N=1,560) | Viremic (N=719) | |
| | | | | Not sequenced (n=172) | Sequenced (n=547) |
| *Gender identity* | Man | 7565 (50.1) | 710 (45.5) | 67 (39.0) | 214 (39.1) |
| | Woman | 7526 (49.9) | 850 (54.5) | 105 (61.0) | 333 (60.9) |
| | Trans | 5 (0.0) | 0.0 (0.0) | (0.0) | 0.0 (0.0) |
| *Age group* | <25 | 6439 (42.7) | 512 (32.8) | 51 (29.7) | 238 (43.5) |
| | 25-29 | 4298 (28.5) | 481 (30.8) | 62 (36.0) | 162 (29.6) |
| | 30-34 | 2336 (15.5) | 288 (18.5) | 31 (18.0) | 72 (13.2) |
| | 35+ | 2023 (13.4) | 279 (17.9) | 28 (16.3) | 75 (13.7) |
| *Key population* | FSW | 4178 (27.7) | 441 (28.3) | 51 (29.7) | 185 (33.8) |
| | MSM | 3423 (22.7) | 567 (36.3) | 53 (30.8) | 176 (32.2) |
| | PWID | 4089 (27.1) | 152 (9.7) | 23 (13.4) | 51 (9.3) |
| | Transgender people | 3406 (22.6) | 400 (25.6) | 45 (26.2) | 135 (24.7) |
| *Geopolitical zone* | North-Central | 2511 (16.6) | 332 (21.3) | 39 (22.7) | 75 (13.7) |
| | North-East | 2359 (15.6) | 254 (16.3) | 18 (10.5) | 78 (14.3) |
| | North-West | 2694 (17.8) | 207 (13.3) | 9 (5.2) | 79 (14.4) |
| | South-East | 2783 (18.4) | 144 (9.2) | 23 (13.4) | 69 (12.6) |
| | South-South | 2388 (15.8) | 267 (17.1) | 38 (22.1) | 109 (19.9) |
| | South-West | 2361 (15.6) | 356 (22.8) | 45 (26.2) | 137 (25.0) |
| *Highest level of education obtained* | Secondary or less | 11680 (77.4) | 1115 (71.5) | 118 (68.6) | 427 (78.1) |
| | Tertiary | 3416 (22.6) | 445 (28.5) | 54 (31.4) | 120 (21.9) |
| *Marital status* | Non-single | 3015 (20.0) | 372 (23.8) | 33 (19.2) | 105 (19.2) |

| | | | | | |
|---|---|---|---|---|---|
| | Single | 12081 (80.0) | 1188 (76.2) | 139 (80.8) | 442 (80.8) |
| *Employment status* | Employed /Other | 7069 (46.8) | 793 (50.8) | 93 (54.1) | 272 (49.7) |
| | Unemployed | 5729 (38.0) | 571 (36.6) | 60 (34.9) | 203 (37.1) |
| | Student/Retired/DK/NR | 2298 (15.2) | 196 (12.6) | 19 (11.0) | 72 (13.2) |
| *Location typology* | Nightlife/sex venue | 4239 (28.1) | 504 (32.3) | 65 (37.8) | 197 (36.0) |
| | Residential/private | 5650 (37.4) | 660 (42.3) | 73 (42.4) | 228 (41.7) |
| | Street/virtual/other | 5207 (34.5) | 396 (25.4) | 34 (19.8) | 122 (22.3) |
| *Knows of a place to receive HIV counselling and testing* | Yes | 6645 (44.0) | 974 (62.4) | 108 (62.8) | 289 (52.8) |
| | No | 7632 (50.6) | 531 (34.0) | 61 (35.5) | 234 (42.8) |
| | DK/NR | 819 (5.4) | 55 (3.5) | 3 (1.7) | 24 (4.4) |
| *Contacted by an outreach worker to provide HIV/AIDS services in past year* | Yes | 3816 (25.3) | 678 (43.5) | 79 (45.9) | 178 (32.5) |
| | No | 10581 (70.1) | 811 (52.0) | 85 (49.4) | 344 (62.9) |
| | DK/NR | 699 (4.6) | 71 (4.6) | 8 (4.7) | 25 (4.6) |
| *Received most recent HIV test within the past year* | Yes | 8530 (56.5) | 1106 (70.9) | 121 (70.3) | 368 (67.3) |
| | No | 2991 (19.8) | 263 (16.9) | 33 (19.2) | 93 (17.0) |
| | DK/NR | 3575 (23.7) | 191 (12.2) | 18 (10.5) | 86 (15.7) |
| *HIV viral load (copies/mL)* | <10,000 | -- | -- | 113 (65.7) | 166 (30.3) |
| | 10,000–49,999 | -- | -- | 32 (18.6) | 168 (30.7) |
| | ≥50,000 | -- | -- | 27 (15.7) | 213 (38.9) |
| *HIV subtype* | CRF02_AG | -- | -- | -- | 369 (67.5) |
| | G | -- | -- | -- | 141 (25.8) |
| | CPX | -- | -- | -- | 20 (3.7) |
| | A | -- | -- | -- | 17 (3.1) |

All data presented as *n* (column %). "DK/NR" indicates "Don't Know/No Response" and includes missing responses. Non-single includes currently married and divorced/separated/widowed

**Table S5. Reference sequence IDs obtained from the Los Alamos National Laboratory (LANL) HIV Sequence Repository.**

| LANL ID | HIV subtype |
|---|---|
| 02_AG.NG.2016.R3.MT036498 | CRF02_AG |
| 02_AG.NG.2015.E03-0161.OR508441 | CRF02_AG |
| 02_AG.NG.2015.E03-0160.OR508440 | CRF02_AG |
| 02_AG.NG.2015.E03-0158.OR508432 | CRF02_AG |
| 02_AG.NG.2015.E03-0147.OR508382 | CRF02_AG |
| 02_AG.NG.2015.E03-0114.OR508266 | CRF02_AG |
| 02_AG.NG.2015.E03-0111.OR508253 | CRF02_AG |
| 02_AG.NG.2015.E03-0108.OR508251 | CRF02_AG |
| 02_AG.NG.2015.E03-0104.OR508244 | CRF02_AG |
| 02_AG.NG.2015.E03-0096.OR508231 | CRF02_AG |
| 02_AG.NG.2015.E03-0060.OR508106 | CRF02_AG |
| 02_AG.NG.2015.E03-0051.OR508050 | CRF02_AG |
| 02_AG.NG.2015.E03-0040.OR507981 | CRF02_AG |
| 02_AG.NG.2015.E03-0025.OR507907 | CRF02_AG |
| 02_AG.NG.2014.E03-0004.OR508538 | CRF02_AG |
| 02_AG.NG.2014.E03-0020.OR508618 | CRF02_AG |
| 02_AG.NG.2014.E01-0076.OR508384 | CRF02_AG |
| 02_AG.NG.2014.E03-0017.OR508604 | CRF02_AG |
| 02_AG.NG.2014.E03-0003.OR508536 | CRF02_AG |
| 02_AG.NG.2014.E01-0085.OR508473 | CRF02_AG |
| 02_AG.NG.2014.E01-0081.OR508442 | CRF02_AG |
| 02_AG.NG.2014.E01-0089.OR508429 | CRF02_AG |
| 02_AG.NG.2014.E01-0075.OR508365 | CRF02_AG |
| 02_AG.NG.2014.E01-0074.OR508362 | CRF02_AG |
| 02_AG.NG.2014.E01-0070.OR508340 | CRF02_AG |
| 02_AG.NG.2014.E01-0069.OR508339 | CRF02_AG |
| 02_AG.NG.2014.E01-0059.OR508233 | CRF02_AG |
| 02_AG.NG.2014.E01-0057.OR508204 | CRF02_AG |
| 02_AG.NG.2014.E01-0029.OR507877 | CRF02_AG |
| 02_AG.NG.2013.ZZRJ103.KC755268 | CRF02_AG |
| 02_AG.NG.2013.E01-0009.OR508638 | CRF02_AG |
| 02_AG.NG.2013.E01-0013.OR508646 | CRF02_AG |
| 02_AG.NG.2013.ZZRJ089.KC755266 | CRF02_AG |
| 02_AG.NG.2013.ZZRJ076.KC755264 | CRF02_AG |
| 02_AG.NG.2013.ZZRJ043.KC755259 | CRF02_AG |
| 02_AG.NG.2013.ZZRJ035.KC755256 | CRF02_AG |
| 02_AG.NG.2013.ZZRJ032.KC755254 | CRF02_AG |
| 02_AG.NG.2013.ZZRJ025.KC755251 | CRF02_AG |

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|---|---|
| 02_AG.NG.2013.ZZRJ019.KC755248 | CRF02_AG |
| 02_AG.NG.2013.ZZRJ015.KC755246 | CRF02_AG |
| 02_AG.NG.2013.ZZRJ014.KC755245 | CRF02_AG |
| 02_AG.NG.2013.ZZRJ011.KC755243 | CRF02_AG |
| 02_AG.NG.2013.ZZRJ010.KC755242 | CRF02_AG |
| 02_AG.NG.2013.ZZRJ002.KC755237 | CRF02_AG |
| 02_AG.NG.2012.12NG060418.KX389649 | CRF02_AG |
| 02_AG.NG.2012.12NG060304.KX389647 | CRF02_AG |
| 02_AG.NG.2012.CP107100197.KX139401 | CRF02_AG |
| 02_AG.NG.2012.CP107100207.KX139399 | CRF02_AG |
| 02_AG.NG.2012.CP107100202.KX139395 | CRF02_AG |
| 02_AG.NG.2012.CP107100182.KX139394 | CRF02_AG |
| 02_AG.NG.2012.CP107100190.KX139392 | CRF02_AG |
| 02_AG.NG.2012.CP107100215.KX139390 | CRF02_AG |
| 02_AG.NG.2012.CP107100203.KX139388 | CRF02_AG |
| 02_AG.NG.2012.CP107100069.KX139387 | CRF02_AG |
| 02_AG.NG.2012.CP107100045.KX139385 | CRF02_AG |
| 02_AG.NG.2012.CP107100240.KX139384 | CRF02_AG |
| 02_AG.NG.2012.CP107100047.KX139383 | CRF02_AG |
| 02_AG.NG.2012.CP107100050.KX139378 | CRF02_AG |
| 02_AG.NG.2012.CP107100214.KX139377 | CRF02_AG |
| 02_AG.NG.2012.CP107100237.KX139376 | CRF02_AG |
| 02_AG.NG.2012.CP107100042.KX139370 | CRF02_AG |
| 02_AG.NG.2012.CP107100089.KX139367 | CRF02_AG |
| 02_AG.NG.2012.CP107100062.KX139366 | CRF02_AG |
| 02_AG.NG.2012.CP107100064.KX139364 | CRF02_AG |
| 02_AG.NG.2012.CP107100079.KX139363 | CRF02_AG |
| 02_AG.NG.2012.CP107100075.KX139362 | CRF02_AG |
| 02_AG.NG.2012.CP107100105.KX139360 | CRF02_AG |
| 02_AG.NG.2012.CP107100080.KX139358 | CRF02_AG |
| 02_AG.NG.2012.CP107100110.KX139357 | CRF02_AG |
| 02_AG.NG.2012.CP107100085.KX139356 | CRF02_AG |
| 02_AG.NG.2012.CP107100087.KX139354 | CRF02_AG |
| 02_AG.NG.2012.CP107100206.KX139353 | CRF02_AG |
| 02_AG.NG.2012.CP107100084.KX139352 | CRF02_AG |
| 02_AG.NG.2012.CP107100106.KX139347 | CRF02_AG |
| 02_AG.NG.2012.CP107100125.KX139346 | CRF02_AG |
| 02_AG.NG.2012.CP107100107.KX139345 | CRF02_AG |
| 02_AG.NG.2012.CP107100130.KX139344 | CRF02_AG |
| 02_AG.NG.2012.CP107100140.KX139343 | CRF02_AG |
| 02_AG.NG.2012.CP107100123.KX139339 | CRF02_AG |

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|---|---|
| 02_AG.NG.2012.CP107100112.KX139336 | CRF02_AG |
| 02_AG.NG.2012.CP107100111.KX139335 | CRF02_AG |
| 02_AG.NG.2012.CP107100005.KX139332 | CRF02_AG |
| 02_AG.NG.2012.CP107100006.KX139330 | CRF02_AG |
| 02_AG.NG.2012.CP107100009.KX139328 | CRF02_AG |
| 02_AG.NG.2012.CP107100019.KX139324 | CRF02_AG |
| 02_AG.NG.2012.CP107100031.KX139319 | CRF02_AG |
| 02_AG.NG.2012.CP107100012.KX139318 | CRF02_AG |
| 02_AG.NG.2012.CP107100037.KX139317 | CRF02_AG |
| 02_AG.NG.2012.CP107100027.KX139316 | CRF02_AG |
| 02_AG.NG.2012.CP107100033.KX139315 | CRF02_AG |
| 02_AG.NG.2012.CP107100028.KX139314 | CRF02_AG |
| 02_AG.NG.2012.CP107100039.KX139313 | CRF02_AG |
| 02_AG.NG.2012.CP107100203.KX073710 | CRF02_AG |
| 02_AG.NG.2012.CP107100105.KX073708 | CRF02_AG |
| 02_AG.NG.2012.CP107100019.KX073704 | CRF02_AG |
| 02_AG.NG.2011.LN2369.KF241493 | CRF02_AG |
| 02_AG.NG.2011.LN2860.KF241486 | CRF02_AG |
| 02_AG.NG.2011.11NG050366.KX389644 | CRF02_AG |
| 02_AG.NG.2011.11NG050356.KX389643 | CRF02_AG |
| 02_AG.NG.2011.LN0911.KF241494 | CRF02_AG |
| 02_AG.NG.2011.11NG050135.KX389640 | CRF02_AG |
| 02_AG.NG.2011.LL4420.KF241479 | CRF02_AG |
| 02_AG.NG.2011.DE00211NG010.KY953198 | CRF02_AG |
| 02_AG.NG.2011.DE00211NG009.KY953197 | CRF02_AG |
| 02_AG.NG.2010.PJ9959.KF241498 | CRF02_AG |
| 02_AG.NG.2010.10NG030161.KX389610 | CRF02_AG |
| 02_AG.NG.2010.10NG020437.KX389614 | CRF02_AG |
| 02_AG.NG.2010.10NG020307.KX389617 | CRF02_AG |
| 02_AG.NG.2010.10NG020065.KX389621 | CRF02_AG |
| 02_AG.NG.2010.NG_DOC_13816.HQ845960 | CRF02_AG |
| 02_AG.NG.2010.NG_DOC_13772.HQ845956 | CRF02_AG |
| 02_AG.NG.2010.NG_DOC_13767.HQ845955 | CRF02_AG |
| 02_AG.NG.2010.NG_DOC_13740.HQ845951 | CRF02_AG |
| 02_AG.NG.2010.NG_DOC_13712.HQ845946 | CRF02_AG |
| 02_AG.NG.2010.NG_DOC_13662.HQ845943 | CRF02_AG |
| 02_AG.NG.2010.NG_DOC_13655.HQ845942 | CRF02_AG |
| 02_AG.NG.2009.LN8580.KF241492 | CRF02_AG |
| 02_AG.NG.2009.LN4321.KF241489 | CRF02_AG |
| 02_AG.NG.2009.09NG010325.KX389624 | CRF02_AG |
| 02_AG.NG.2009.09NG010170.KX389630 | CRF02_AG |

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| 06_cpx.NG.2013.ABW72667.MK784452 | 06_cpx |
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| 06_cpx.NG.2011.LN9690.KF241491 | 06_cpx |

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| 06_cpx.NG.2008.LL5309.KF241462 | 06_cpx |
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**Table S6.** Location typology distribution among sequenced samples by phylogenetic cluster membership; Nigerian IBBSS (2020).

| | **Total (sequenced, N = 547)** | **Non-clustering (N=405)** | **Clustering (N=142)** |
|---|---|---|---|
| *FSW* | 185 (100.0) | 173 (100.0) | 12 (100.0) |
| Nightlife/Sex venue | 107 (57.8) | 97 (56.1) | 10 (83.3) |
| Residential/Private | 56 (30.3) | 55 (31.8) | 1 (8.3) |
| Street/Virtual/Other | 22 (11.9) | 21 (12.1) | 1 (8.3) |
| *MSM* | 176 (100.0) | 108 (100.0) | 68 (100.0) |
| Nightlife/Sex venue | 37 (21.0) | 22 (20.4) | 15 (22.1) |
| Residential/Private | 93 (52.8) | 58 (53.7) | 35 (51.5) |
| Street/Virtual/Other | 46 (26.1) | 28 (25.9) | 18 (26.5) |
| *PWID* | 51 (100.0) | 47 (100.0) | 4 (100.0) |
| Nightlife/Sex venue | 5 (9.8) | 5 (10.6) | 0 (0.0) |
| Residential/Private | 30 (58.8) | 26 (55.3) | 4 (100.0) |
| Street/Virtual/Other | 16 (31.4) | 16 (34.0) | 0 (0.0) |
| *Transgender* | 135 (100.0) | 77 (100.0) | 58 (100.0) |
| Nightlife/Sex venue | 48 (35.6) | 19 (24.7) | 29 (50.0) |
| Residential/Private | 49 (36.3) | 33 (42.9) | 16 (27.6) |
| Street/Virtual/Other | 38 (28.1) | 25 (32.5) | 13 (22.4) |
| All data presented as *n* (%) | | | |

**Table S7.** Sequence data for phylodynamic modelling by HIV subtype, key population group, and geopolitical zone; Nigerian IBBSS (2020).

| | All | FSW | MSM | PWID | Transgender |
|---|---|---|---|---|---|
| | **Subtype CRF02_AG, N (Col %)** | | | | |
| **All geopolitical zones** | **364 (100.0)** | **96 (100.0)** | **132 (100.0)** | **29 (100.0)** | **107 (100.0)** |
| Northern | 128 (35.2) | 45 (46.9) | 26 (19.7) | 14 (48.3) | 43 (40.2) |
| North-Central (NC) | 45 (12.4) | 12 (12.5) | 10 (7.6) | 7 (24.1) | 16 (15.0) |
| North-East (NE) | 43 (11.8) | 11 (11.5) | 9 (6.8) | 4 (13.8) | 19 (17.8) |
| North-West (NW) | 40 (11.0) | 22 (22.9) | 7 (5.3) | 3 (10.3) | 8 (7.5) |
| Southern | 236 (64.8) | 64.8 (51) | 106 (80.3) | 15 (51.7) | 64 (59.8) |
| South-East (SE) | 51 (14.0) | 16 (16.7) | 21 (15.9) | 3 (10.3) | 11 (10.3) |
| South-South (SS) | 76 (20.9) | 18 (18.8) | 37 (28.0) | 7 (24.1) | 14 (13.1) |
| South-West (SW) | 109 (29.9) | 17 (17.7) | 48 (36.4) | 5 (17.2) | 39 (36.4) |
| | **Subtype G, N (Col %)** | | | | |
| **All geopolitical zones** | **139 (100.0)** | **74 (100.0)** | **28 (100.0)** | **18 (100.0)** | **19 (100.0)** |
| Northern | 73 (52.5) | 47 (63.5) | 7 (25.0) | 10 (34.5) | 9 (47.4) |
| North-Central (NC) | 20 (14.4) | 14 (18.9) | 2 (7.1) | 2 (11.1) | 2 (10.5) |
| North-East (NE) | 27 (19.4) | 15 (20.3) | 4 (14.3) | 4 (22.2) | 4 (21.1) |
| North-West (NW) | 26 (18.7) | 18 (24.3) | 1 (3.6) | 4 (22.2) | 3 (15.8) |
| Southern | 66 (47.5) | 27 (36.5) | 21 (75.0) | 8 (27.6) | 10 (52.6) |
| South-East (SE) | 16 (11.5) | 10 (13.5) | 3 (10.7) | 1 (5.6) | 2 (10.5) |
| South-South (SS) | 29 (20.9) | 12 (16.2) | 9 (32.1) | 4 (22.2) | 4 (21.1) |
| South-West (SW) | 21 (15.1) | 5 (6.8) | 9 (32.1) | 3 (16.7) | 4 (21.1) |

**Table S8.** Posterior estimates of molecular clock rates for HIV subtypes CRF02_AG and G generated from Bayesian Skyline Plots constructed from key populations living with HIV; Nigerian IBBSS (2020).

| | **Subtype CRF02_AG (N=364)** | **Subtype G (N=139)** |
|---|---|---|
| Posterior HIV clock rate, substitutions/site/year | $3.3984 \times 10^{-3}$ | $3.2501 \times 10^{-3}$ |

**Table S9.** Key population size estimates by geopolitical zone; multiple sources.

| | FSW | MSM | PWID | TG[a] | Total | Total (Log10) | Source[b] |
|---|---|---|---|---|---|---|---|
| **Population size estimates, n** | | | | | | | |
| North | | | | | 293722 | **5.47** | -- |
| North-Central (NC) | 102300 | 15800 | 59000 | 3249 | 180349 | **5.26** | Capture-recapture (2018)[128] |
| North-East (NE) | 9235 | 3063 | 7657 | 4655 | 24610 | **4.39** | KPSE (2018)[108] |
| North-West (NW) | 35622 | 29005 | 16091 | 9046 | 89764 | **4.95** | KPSE (2018)[108] |
| South | | | | | 460486 | **5.66** | -- |
| South-East (SE) | 44527 | 25806 | 6941 | 3720 | 80994 | **4.91** | KPSE (2018)[108] |
| South-South (SS) | 78800 | 76000 | 36800 | 4268 | 195868 | **5.29** | Capture-recapture (2018) [128] |
| South-West (SW) | 59442 | 85381 | 35441 | 3360 | 183624 | **5.26** | Capture-recapture (2018) [128]/ KPSE (2018)[108] |
| Total | 329926 | 235055 | 161930 | 28297 | 755208 | **5.88** | -- |
| Total (Log10) | **5.52** | **5.37** | **5.21** | **4.45** | **5.88** | | |

[a] Transgender people were not included in the 2018 KPSE or Capture-recapture, thus the 2023 KPSE was used[129], which utilized different states for each geopolitical zone than the 2020 IBBSS. Therefore, population counts for transgender people were extrapolated by summing size estimates from all states in each zone, calculating the average, and multiplying it by two (for two states in a zone), to best resemble estimates from other key population groups.
[b] For FSW, MSM, and PWID, data were interpolated from the 2018 KPSE and 2018 capture-recapture. Key population counts were generated by summing size estimates from select states that aligned with the 2020 IBBSS.

**Table S10.** Inferred HIV subtype CRF02_AG and G median ancestral migration events between key population groups; Nigerian IBBSS (2020).

| | **Subtype CRF02_AG** | | **Subtype G** | |
|---|---|---|---|---|
| **Direction** | Median number of ancestral migration events (events [n=] from group *x* to group *y*) | [95% HPD] of median number of ancestral migration events (+/- events [n=] from group *x* to group *y*) | Median number of ancestral migration events (events [n=] from group *x* to group *y*) | 95% HPD of median number of ancestral migration events (+/- events [n=] from group *x* to group *y*) |
| FSW → MSM | 0.55 | [9.58x10$^{-6}$, 2.04] | **3.45** | [4.36 x10$^{-4}$, 6.77] |
| FSW → PWID | **7.53** | [4.82, 10.65] | **4.05** | [0.33, 7.84] |
| FSW → Transgender | 0.24 | [1.04 x10$^{-5}$, 0.98] | 0.55 | [3.49x10$^{-5}$, 2.17] |
| MSM → FSW | 0.11 | [1.37x10$^{-6}$, 0.50] | 0.29 | [4.43x10$^{-6}$, 1.27] |
| MSM → PWID | 0.19 | [6.24 x10$^{-6}$, 0.85] | 0.51 | [1.23x10$^{-5}$, 2.48] |
| MSM → Transgender | **14.03** | [10.51, 17.99] | **7.14** | [3.89, 10.87] |
| PWID → FSW | 0.27 | [2.27x10$^{-6}$, 1.17] | 0.33 | [5.98x10$^{-6}$, 1.55] |
| PWID → MSM | **6.28** | [1.92, 9.85] | **1.47** | [2.02 x10$^{-5}$, 7.44] |
| PWID → Transgender | 0.99 | [1.24 x10$^{-4}$, 3.65] | **4.70** | [0.23, 7.95] |
| Transgender → FSW | 0.06 | [3.97x10$^{-6}$, 0.26] | 0.07 | [1.41x10$^{-6}$, 0.29] |
| Transgender → MSM | **1.72** | [0.28, 3.56] | 0.13 | [1.29x10$^{-5}$, 0.58] |
| Transgender → PWID | 0.12 | [1.88 x10$^{-5}$, 0.47] | 0.09 | [7.20x10$^{-7}$, 0.41] |
| Median number of ancestral migration events ≥ 1 are indicated in **bold** text. | | | | |

**Table S11.** Inferred HIV subtype CRF02_AG and G median ancestral migration events between northern and southern geopolitical zones among key populations; Nigerian IBBSS (2020).

| | **Subtype CRF02_AG** | | **Subtype G** | |
|---|---|---|---|---|
| **Direction** | Median number of ancestral migration events (events [n=] from group *x* to group *y*) | [95% HPD] of median number of ancestral migration events (+/- events [n=] from group *x* to group *y*) | Median number of ancestral migration events (events [n=] from group *x* to group *y*) | [95% HPD] of median number of ancestral migration events (+/- events [n=] from group *x* to group *y*) |
| North→ South | 0.14 | [0.01, 0.33] | **3.68** | [2.33, 5.24] |
| South→ North | **1.87** | [1.29, 2.55] | 0.05 | [4.14 x$10^{-6}$, 0.22] |

Mean number of ancestral migration events ≥ 1 are indicated in **bold** text.
"North" comprises North-Central, North-East, and North-West zones. "South" comprises South-South, South-East, and South-West zones.

## APPENDIX F: Objective 2, Supplemental Figures

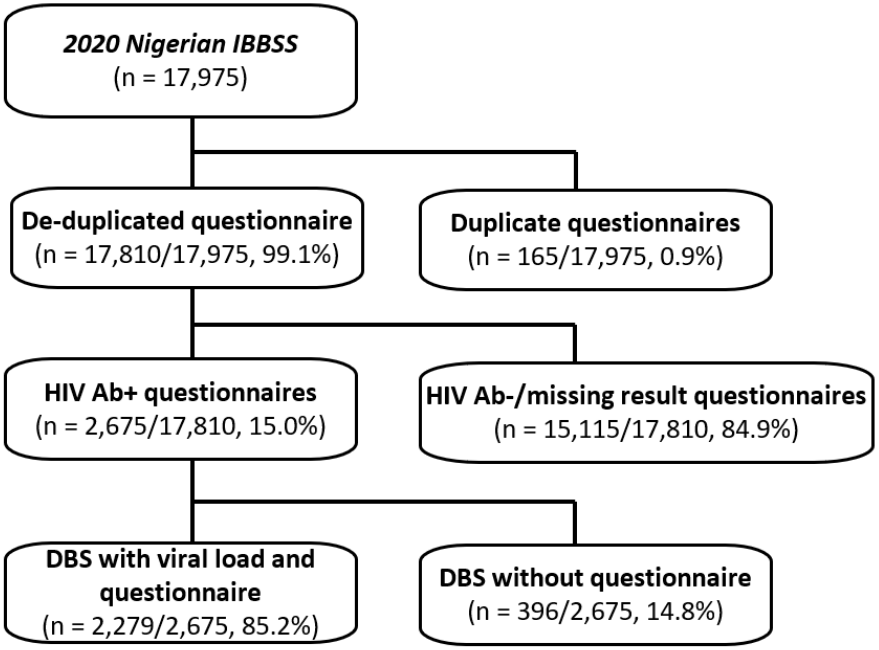


**Figure S1.** Questionnaire data cleaning and data linkage workflow; Nigerian IBBSS (2020).

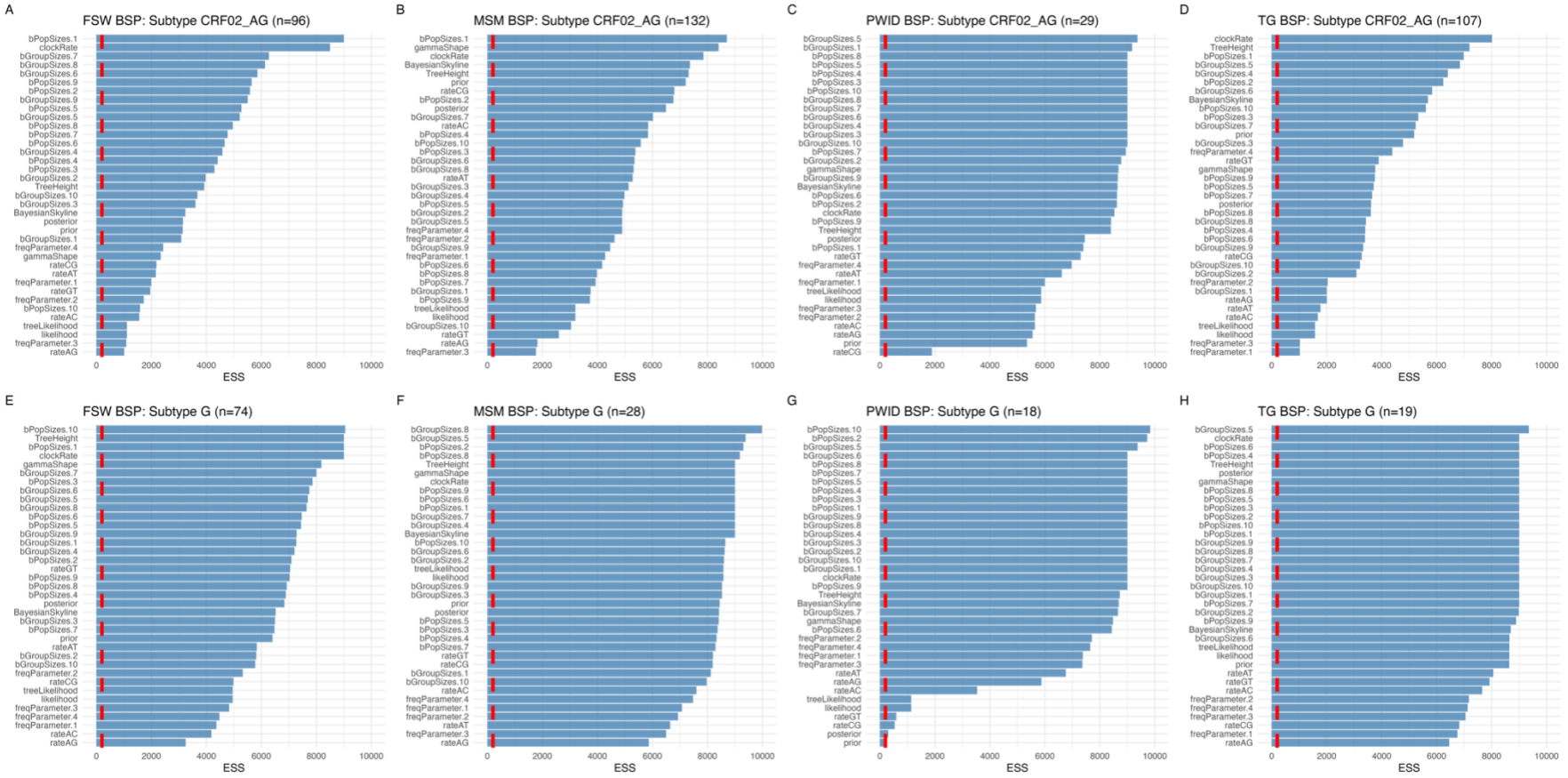


**Figure S2.** Effective sample size (ESS) model diagnostics of Bayesian Skyline Plots (Bayesian skyline plots), by key population group and HIV subtype; Nigerian IBBSS (2020). Y-axis values are model statistics, while X-axis is ESS values. HIV subtype CRF02_AG (panels A-D) and G (panels E-H). The vertical dashed red line marks an ESS value of 200, the minimum threshold for an

acceptable amount of mixing between model parameters. All models were run for 300,000,000 Markov Chain Monte-Carlo (MCMC) chains.

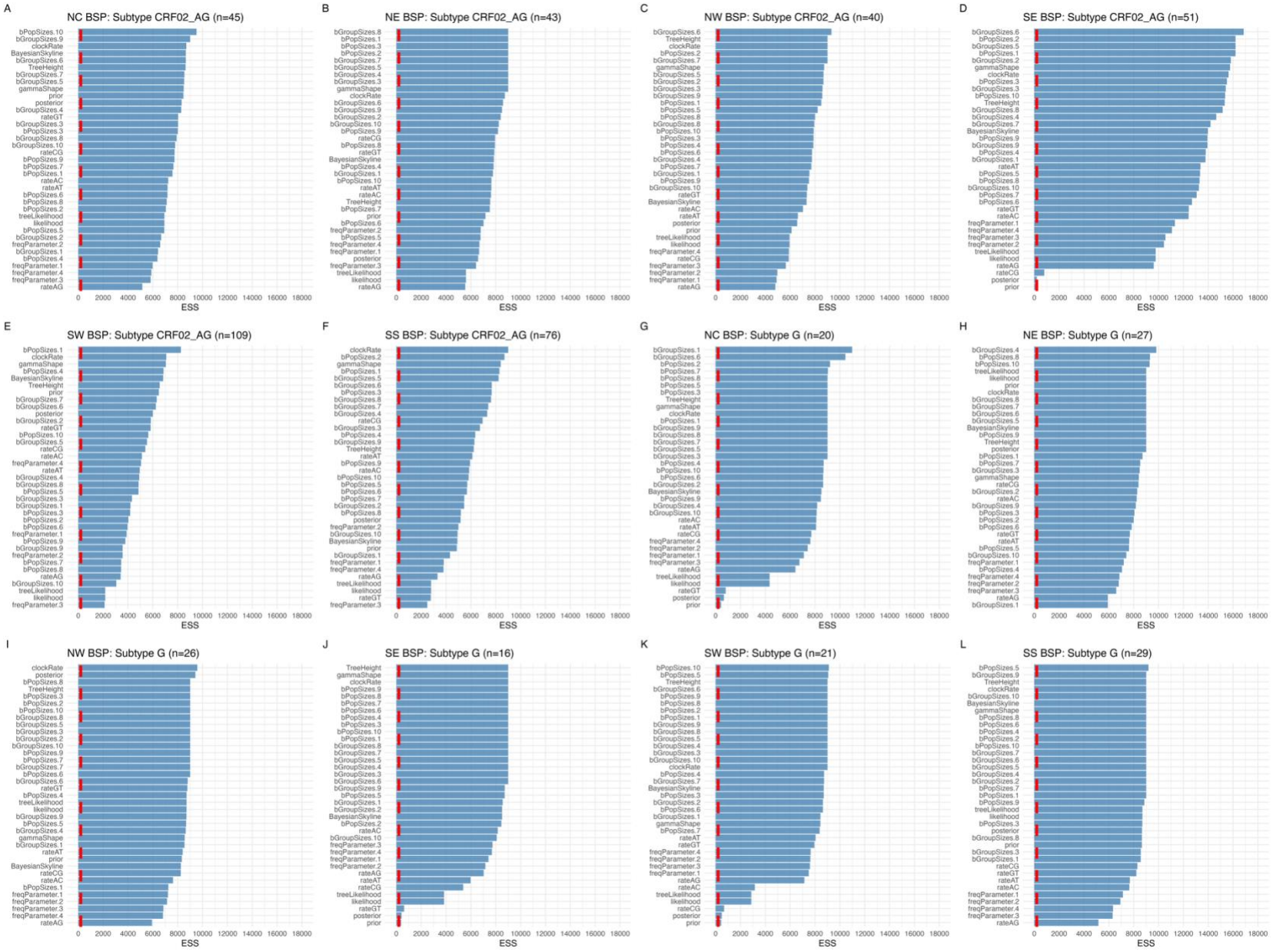
A
NC BSP: Subtype CRF02_AG (n=45)
bPopSizes.10
bGroupSizes.9
clockRate
BayesianSkyline
bGroupSizes.6
TreeHeight
bGroupSizes.7
bGroupSizes.5
gammaShape
prior
posterior
bGroupSizes.4
rateGT
bGroupSizes.3
bPopSizes.3
bGroupSizes.8
bGroupSizes.10
rateCG
bPopSizes.9
bPopSizes.7
bPopSizes.1
rateAC
rateAT
bPopSizes.6
bPopSizes.8
bPopSizes.2
treeLikelihood
likelihood
bPopSizes.5
bGroupSizes.2
freqParameter.2
bGroupSizes.1
bPopSizes.4
freqParameter.1
freqParameter.4
freqParameter.3
rateAG
0 2000 4000 6000 8000 10000 12000 14000 16000 18000
ESS
B
NE BSP: Subtype CRF02_AG (n=43)
bGroupSizes.8
bPopSizes.1
bPopSizes.3
bPopSizes.2
bGroupSizes.7
bGroupSizes.5
bGroupSizes.4
gammaShape
clockRate
bGroupSizes.6
bGroupSizes.9
bGroupSizes.2
bGroupSizes.10
bPopSizes.9
rateCG
bPopSizes.8
rateGT
BayesianSkyline
bPopSizes.4
bGroupSizes.1
bPopSizes.10
rateAT
rateAC
TreeHeight
bPopSizes.7
prior
bPopSizes.6
freqParameter.2
bPopSizes.5
freqParameter.4
freqParameter.1
posterior
freqParameter.3
treeLikelihood
likelihood
rateAG
0 2000 4000 6000 8000 10000 12000 14000 16000 18000
ESS
C
NW BSP: Subtype CRF02_AG (n=40)
bGroupSizes.6
TreeHeight
clockRate
bPopSizes.2
bGroupSizes.7
gammaShape
bGroupSizes.5
bPopSizes.5
bGroupSizes.3
bGroupSizes.9
bPopSizes.1
bPopSizes.5
bPopSizes.8
bGroupSizes.8
bPopSizes.10
bPopSizes.3
bPopSizes.4
bPopSizes.6
bGroupSizes.4
bPopSizes.7
bGroupSizes.1
bPopSizes.9
bGroupSizes.10
rateGT
BayesianSkyline
rateAC
rateAT
posterior
prior
treeLikelihood
likelihood
freqParameter.4
rateCG
freqParameter.2
freqParameter.1
rateAG
0 2000 4000 6000 8000 10000 12000 14000 16000 18000
ESS
D
SE BSP: Subtype CRF02_AG (n=51)
bGroupSizes.6
bPopSizes.2
bGroupSizes.5
bPopSizes.1
bGroupSizes.2
gammaShape
clockRate
bPopSizes.3
bGroupSizes.3
bPopSizes.10
TreeHeight
bGroupSizes.8
bGroupSizes.4
bGroupSizes.7
BayesianSkyline
bPopSizes.9
bGroupSizes.9
bPopSizes.4
bGroupSizes.1
rateAT
bPopSizes.5
bPopSizes.8
bGroupSizes.10
bPopSizes.7
bPopSizes.6
rateGT
rateAC
freqParameter.1
freqParameter.4
freqParameter.3
freqParameter.2
treeLikelihood
likelihood
rateAG
rateCG
posterior
prior
0 2000 4000 6000 8000 10000 12000 14000 16000 18000
ESS
E
SW BSP: Subtype CRF02_AG (n=109)
bPopSizes.1
clockRate
gammaShape
bPopSizes.4
BayesianSkyline
TreeHeight
prior
bGroupSizes.7
bGroupSizes.6
posterior
bGroupSizes.2
rateGT
bPopSizes.10
bGroupSizes.5
rateCG
rateAC
freqParameter.4
rateAT
bGroupSizes.4
bGroupSizes.8
bPopSizes.5
bGroupSizes.3
bGroupSizes.1
bPopSizes.3
bPopSizes.2
bPopSizes.6
freqParameter.1
bPopSizes.9
bGroupSizes.9
freqParameter.2
bPopSizes.7
bPopSizes.8
rateAG
bGroupSizes.10
treeLikelihood
likelihood
freqParameter.3
0 2000 4000 6000 8000 10000 12000 14000 16000 18000
ESS
F
SS BSP: Subtype CRF02_AG (n=76)
clockRate
bPopSizes.2
gammaShape
bPopSizes.1
bGroupSizes.5
bGroupSizes.6
bPopSizes.3
bGroupSizes.8
bGroupSizes.7
bGroupSizes.4
rateCG
bGroupSizes.3
bPopSizes.4
bGroupSizes.9
TreeHeight
rateAT
bPopSizes.9
rateAC
bPopSizes.10
bPopSizes.5
bPopSizes.6
bPopSizes.7
bGroupSizes.2
bPopSizes.8
posterior
freqParameter.2
bGroupSizes.10
BayesianSkyline
prior
bGroupSizes.1
freqParameter.1
freqParameter.4
rateAG
treeLikelihood
likelihood
rateGT
freqParameter.3
0 2000 4000 6000 8000 10000 12000 14000 16000 18000
ESS
G
NC BSP: Subtype G (n=20)
bGroupSizes.1
bGroupSizes.6
bPopSizes.2
bPopSizes.7
bPopSizes.8
bPopSizes.5
bPopSizes.3
TreeHeight
gammaShape
clockRate
bPopSizes.1
bGroupSizes.9
bGroupSizes.8
bGroupSizes.7
bGroupSizes.5
bGroupSizes.3
bPopSizes.4
bPopSizes.10
bPopSizes.6
bGroupSizes.2
BayesianSkyline
bPopSizes.9
bGroupSizes.4
bGroupSizes.10
rateAC
rateAT
rateCG
freqParameter.4
freqParameter.2
freqParameter.1
freqParameter.3
rateAG
treeLikelihood
likelihood
rateGT
posterior
prior
0 2000 4000 6000 8000 10000 12000 14000 16000 18000
ESS
H
NE BSP: Subtype G (n=27)
bGroupSizes.4
bPopSizes.8
bPopSizes.10
treeLikelihood
likelihood
prior
clockRate
bGroupSizes.8
bGroupSizes.7
bGroupSizes.6
bGroupSizes.5
BayesianSkyline
bPopSizes.9
TreeHeight
posterior
bPopSizes.1
bPopSizes.7
bGroupSizes.3
gammaShape
rateCG
bGroupSizes.2
rateAC
bGroupSizes.9
bPopSizes.3
bPopSizes.2
bPopSizes.6
rateGT
rateAT
bPopSizes.5
bGroupSizes.10
freqParameter.1
bPopSizes.4
freqParameter.4
freqParameter.2
freqParameter.3
rateAG
bGroupSizes.1
0 2000 4000 6000 8000 10000 12000 14000 16000 18000
ESS
I
NW BSP: Subtype G (n=26)
clockRate
posterior
bPopSizes.8
TreeHeight
bPopSizes.3
bPopSizes.2
bPopSizes.10
bGroupSizes.8
bGroupSizes.5
bGroupSizes.3
bGroupSizes.2
bGroupSizes.10
bGroupSizes.9
bPopSizes.7
bGroupSizes.7
bPopSizes.6
bGroupSizes.6
rateGT
bPopSizes.4
treeLikelihood
likelihood
bGroupSizes.9
bPopSizes.5
bGroupSizes.4
gammaShape
bGroupSizes.1
rateAT
prior
BayesianSkyline
rateCG
rateAC
bPopSizes.1
freqParameter.1
freqParameter.2
freqParameter.3
freqParameter.4
rateAG
0 2000 4000 6000 8000 10000 12000 14000 16000 18000
ESS
J
SE BSP: Subtype G (n=16)
TreeHeight
gammaShape
clockRate
bPopSizes.9
bPopSizes.8
bPopSizes.7
bPopSizes.6
bPopSizes.4
bPopSizes.1
bPopSizes.3
bPopSizes.10
bPopSizes.2
bGroupSizes.8
bGroupSizes.7
bGroupSizes.5
bGroupSizes.4
bGroupSizes.3
bGroupSizes.6
bGroupSizes.9
bPopSizes.5
bGroupSizes.1
bGroupSizes.2
BayesianSkyline
bPopSizes.2
rateAC
bGroupSizes.10
freqParameter.3
freqParameter.4
freqParameter.1
freqParameter.2
rateAG
rateAT
rateCG
treeLikelihood
likelihood
rateGT
posterior
prior
0 2000 4000 6000 8000 10000 12000 14000 16000 18000
ESS
K
SW BSP: Subtype G (n=21)
bPopSizes.10
bPopSizes.5
TreeHeight
bGroupSizes.6
bPopSizes.9
bPopSizes.8
bPopSizes.2
bPopSizes.1
bGroupSizes.9
bGroupSizes.8
bPopSizes.5
bGroupSizes.4
bGroupSizes.3
bGroupSizes.10
clockRate
bPopSizes.4
bGroupSizes.7
BayesianSkyline
bPopSizes.3
bGroupSizes.2
bPopSizes.6
bGroupSizes.1
gammaShape
bPopSizes.7
rateAT
rateGT
freqParameter.4
freqParameter.1
freqParameter.3
freqParameter.1
rateAG
rateAC
treeLikelihood
likelihood
rateCG
posterior
prior
0 2000 4000 6000 8000 10000 12000 14000 16000 18000
ESS
L
SS BSP: Subtype G (n=29)
bPopSizes.5
bGroupSizes.9
TreeHeight
clockRate
bGroupSizes.10
BayesianSkyline
gammaShape
bPopSizes.8
bPopSizes.6
bPopSizes.4
bPopSizes.2
bPopSizes.10
bGroupSizes.7
bGroupSizes.6
bGroupSizes.5
bGroupSizes.4
bGroupSizes.2
bPopSizes.7
bPopSizes.1
bPopSizes.9
treeLikelihood
likelihood
bPopSizes.3
posterior
bGroupSizes.8
prior
bGroupSizes.3
bGroupSizes.1
rateCG
rateGT
rateAT
rateAC
freqParameter.1
freqParameter.2
freqParameter.4
freqParameter.3
rateAG
0 2000 4000 6000 8000 10000 12000 14000 16000 18000
ESS

**Figure S3.** Effective sample size (ESS) model diagnostics of Bayesian Skyline Plots (Bayesian skyline plots), by geopolitical zone and HIV subtype; Nigerian IBBSS (2020). HIV subtype CRF02_AG (panels A-F) and G (panels G-L). Y axes are model statistics, while X axes are ESS values. The vertical dashed red line marks an ESS value of 200, the minimum threshold for an acceptable amount of mixing between model parameters. All models were run for 300,000,000 Markov Chain Monte-Carlo (MCMC) chains. Geopolitical zones stand for: North-Central (NC), North-East (NE), North-West (NW), South-East (SE), South-South (SS), and South-West (SW).

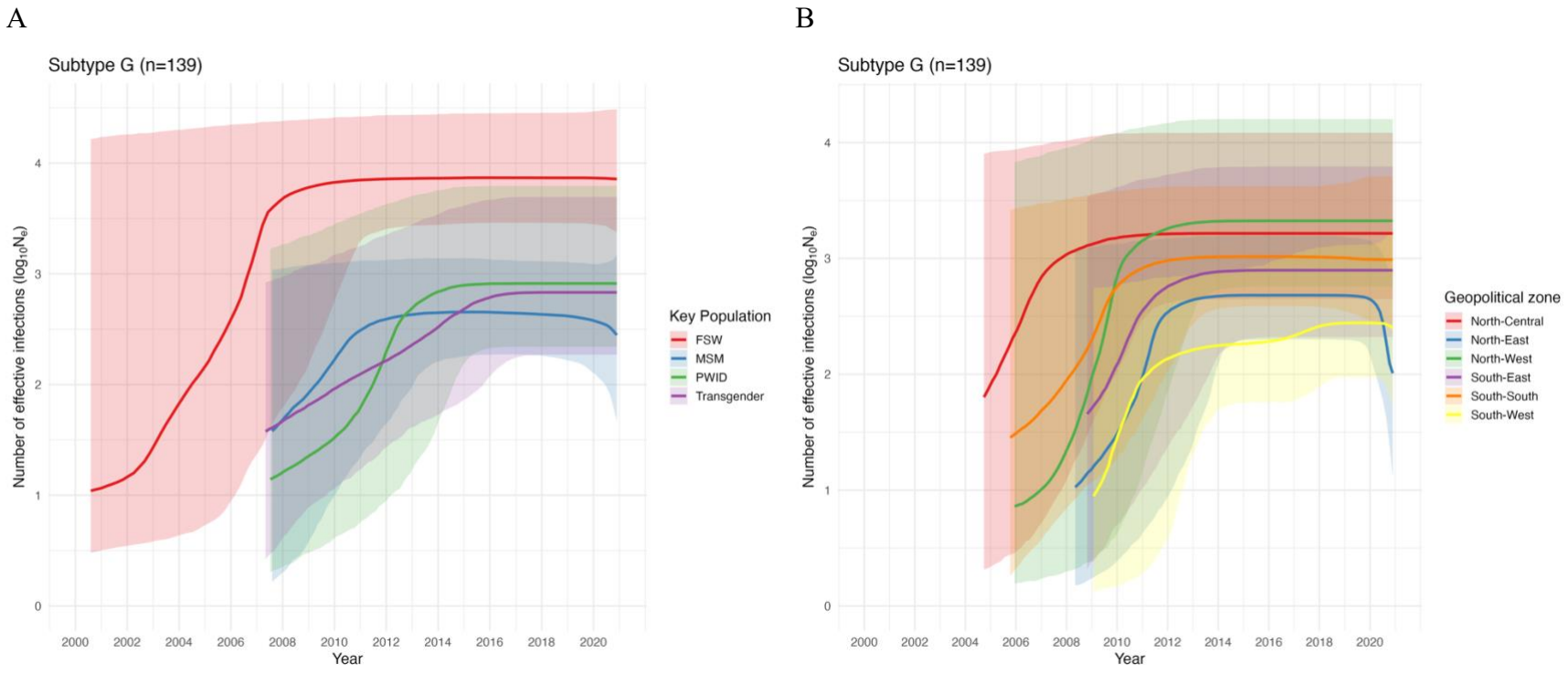


**Figure S4. HIV subtype G: Estimates of median effective population size A) key population groups and B) geopolitical zones; Nigerian IBBSS (2020).** Estimates were produced using coalescent Bayesian skyline plots run with a single seed for 300,000,000 Markov Chain Monte-Carlo (MCMC) chains, where effective sample sizes (ESS) exceeded the minimum acceptable threshold of 200 for all model statistics. The median effective population size is shown by the solid lines, with the 95% highest and lowest posterior densities represented by the shaded area. Key populations stand for: Female sex workers (FSW), men who have sex with men (MSM) and people who inject drugs (PWID).

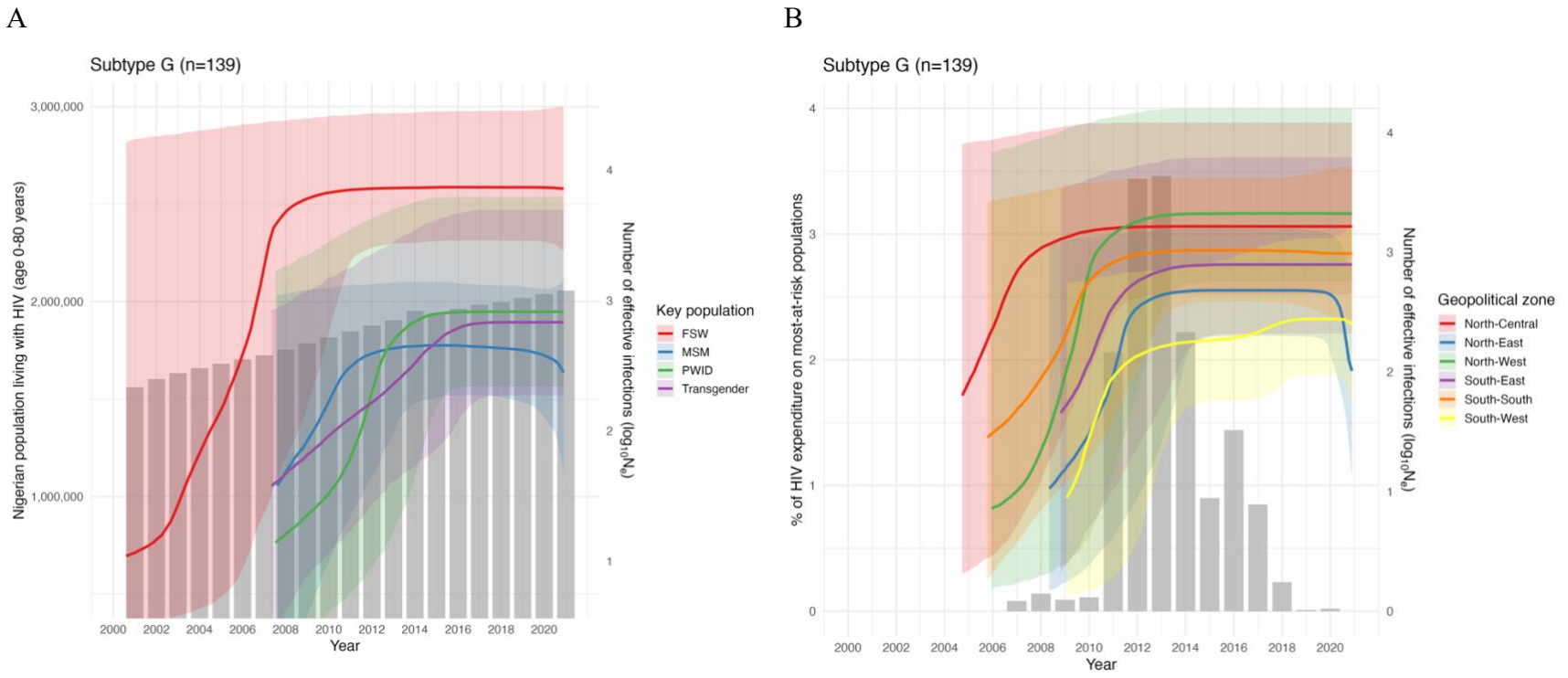


**Figure S5. HIV subtype G: Estimates of median effective population size among A) key populations overlaid with estimated population living with HIV in Nigeria and B) geopolitical zones overlaid with dedicated HIV spending expenditure dedicated to "most-at-risk populations"; Nigerian IBBSS (2020).** Grey columns represent A) Spectrum AIM (https://aim.spectrumweb.org) estimates for population living with HIV aged 0-80 years in Nigeria, and B) the percentage of the yearly HIV expenditure dedicated to "most-at-risk populations", which broadly align with key population groupings. Estimates were produced using coalescent Bayesian

skyline plots run with a single seed for 300,000,000 Markov Chain Monte-Carlo (MCMC) chains, where effective sample sizes (ESS) exceeded the minimum acceptable threshold of 200 for all model statistics. The median effective population size is shown by the solid lines, with the 95% highest and lowest posterior densities represented by the shaded area. Key populations stand for: Female sex workers (FSW), men who have sex with men (MSM) and people who inject drugs (PWID).

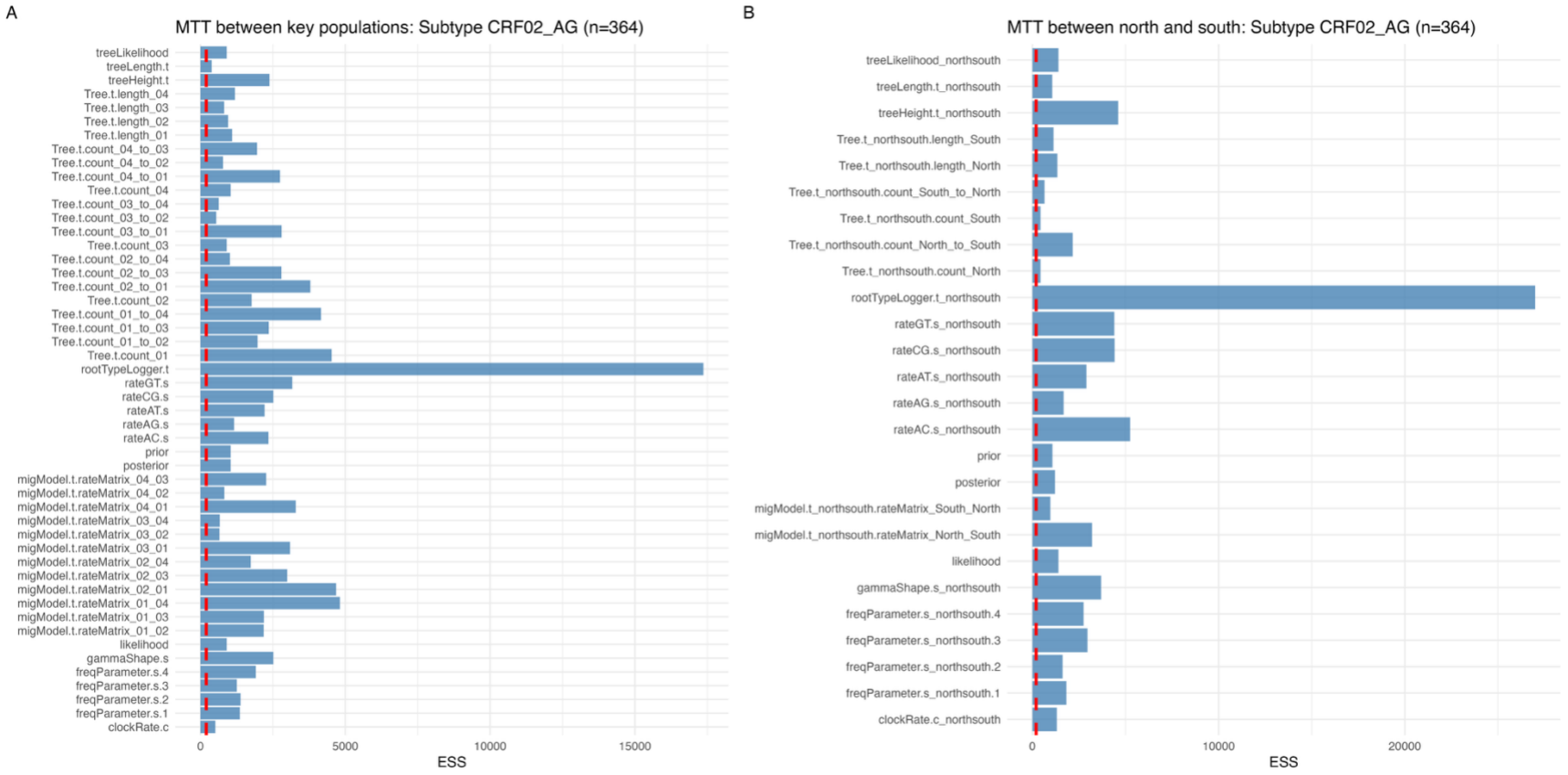


**Figure S6.** HIV subtype CRF02_AG: Effective sample size (ESS) diagnostics of *MultiTypeTree* structured coalescent models; Nigerian IBBSS (2020). Demes were the four key populations (panel A) or six geopolitical zones (panel B). Y axes are model statistics, while X axes are ESS values. The vertical dashed red line marks an ESS value of 200, the threshold for an acceptable amount of mixing between model parameters. Both models were run for 300,000,000 Markov Chain Monte-Carlo (MCMC) chains.

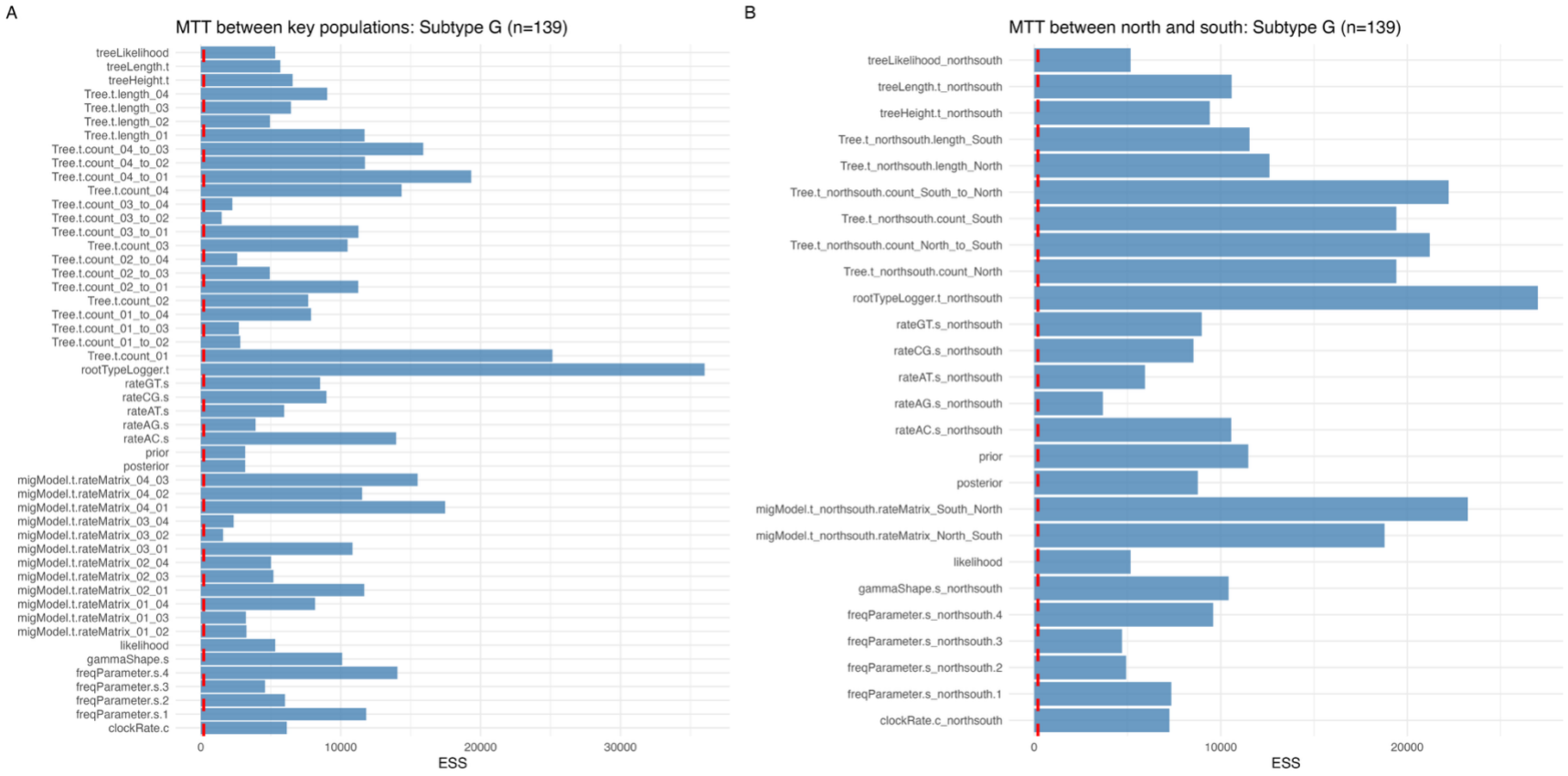


**Figure S7.** HIV subtype G: Effective sample size (ESS) diagnostics of *MultiTypeTree* structured coalescent models; Nigerian IBBSS (2020). Demes were the four key populations (panel A) or six geopolitical zones (panel B). Y axes are model statistics, while X axes are ESS values. The vertical dashed red line marks an ESS value of 200, the threshold for an acceptable amount of mixing between model parameters. Both models were run for 300,000,000 Markov Chain Monte-Carlo (MCMC) chains.