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Research Article

The Likoma Network Study: Context, data collection, and initial results

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The Likoma Network Study: Context, data collection, and initial results

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Abstract

The extent and structure of sexual networks have important consequences for the spread of sexually transmitted diseases such as HIV. However, very few datasets currently exist that allow a detailed investigation of sexual networks in sub-Saharan African settings where HIV epidemics have become generalized. In this paper, we describe the context and methods of the ***Likoma Network Study*** (LNS), one of the few studies that have collected extensive information on sexual networks in sub-Saharan Africa. We start by reviewing theoretical arguments and empirical studies emphasizing the importance of network structures in the epidemiology of HIV and other sexually transmitted infections (STI). The island setting of this study is described, and we argue that the choice of an island as a research site limited potential biases that may make the collection of sexual network data difficult. We then document our empirical strategy for the collection of sexual network data and the subsequent identification of sexual network partners. A description of the protocol for the collection of biomarker data (HIV infection) is provided. Finally, we present initial results relating to the socioeconomic context of the island, the size and composition of sexual networks, the quality of the sexual network data, the determinants of successful contact tracing during the LNS, and the prevalence of HIV in the study population.

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1. Introduction

Sexual networks are the primary mechanism through which HIV is spread in Sub-Saharan Africa (SSA). Theoretical network models have shown that individuals' positions within these sexual networks, and the structural characteristics of the network itself, are important determinants of HIV infection risks and disease dynamics (Kretzschmar and Morris 1996; Ghani and Garnett 2000; Newman 2002). Several features of sexual networks that are predicted by these models to enhance the spread of HIV have been empirically documented in SSA, including *concurrency* of sexual partnerships (Morris 1997) and *skewed distributions* of the number of sexual partnerships (Anderson and May 1991; Jones and Handcock 2003a). Despite this evidence, empirical network studies of HIV infection risks and disease dynamics in SSA remain very limited. Available data on sexual networks are often based on small populations, frequently restricted to egocentric networks, and are not based on an integrated design that includes tracing of sexual networks, HIV testing, and extensive socioeconomic data for all members of a population.

In this paper we provide a comprehensive description and the initial results of the ***Likoma Network Study*** (LNS), an innovative sociocentric network study that documents the sexual networks connecting the young adult population in a sub-Saharan context with high HIV prevalence (see also Helleringer and Kohler 2007, 2008; Helleringer et al. 2007, 2009a, 2009b). As we will elaborate in the subsequent sections, the sociocentric network design of this study allows us to overcome—or at least, ameliorate—several of the limitations that have hampered earlier studies of sexual networks and HIV infection risks in sub-Saharan Africa.

By choosing Likoma Island, a small island on Lake Malawi (Figure 1), as its study location, the LNS follows a long tradition of epidemiological island studies (Cliff, Haggett, and Smallman-Raynor 2000; Whittaker 1999) and takes advantage of the limited range of mobility and the well-defined population boundaries of insular communities: these features imply that a high proportion of the islanders' sexual partners are likely to reside on the island, thereby increasing the probability of tracing sexual partners. Studies using a design similar to that of the LNS have been conducted in different contexts (e.g, Bearman, Moody, and Stovel 2004; Klovdahl et al. 1994), but were lacking for African populations with generalized HIV epidemics. Our presentation of the LNS is structured as follows: *First*, we review empirical and theoretical studies emphasizing the role of network structure in explaining patterns of STI spread within and across populations (Section 2). *Second*, we discuss the practical difficulties and limitations associated with the collection of sociocentric network data, and describe how these difficulties are particularly challenging in a sub-Saharan context (Section 3.1). We then justify the choice of an island setting to conduct a sociocentric network survey, and show how this choice helps ameliorate some of these difficulties (Section 3.2). *Third*, we describe in detail our empirical strategy and

procedures for the identification of sexual networks (Section 4). *Fourth*, we discuss initial results relating to *(i)* the socioeconomic context of the island (Section 5.1), *(ii)* participation in different stages of the study (Section 5.2), *(iii)* sexual behaviors and relationships (Section 5.3), *(iv)* network data quality (Section 5.4), and *(v)* HIV prevalence (Section 5.5).

Figure 1: Likoma Island on Lake Malawi

2. Background: Network epidemiology

The classical models of mathematical epidemiology (Bailey 1975; Anderson and May 1991) rely on the assumption that sexual partners are randomly selected from the population of interest. In this framework, two key measures to study epidemics are (1) the basic reproduction number, R_0, and (2) the final size of an epidemic s_∞. The basic reproduction number, R_0, is the expected number of secondary infections arising from a single, typical infectious individual in a completely susceptible population (Heesterbeek 2002). In a well-mixed and socially unstructured population (i.e., where individuals randomly select their partners among other members of the population), R_0 is the product of three quantities: the transmissibility of the infection τ, the duration of infectiousness δ, and the rate of contact between susceptible and infectious individuals $\bar{c}$. This latter parameter is the focus of the LNS.

Epidemics are nonlinear phenomena and R_0 is a threshold parameter. When $R_0 > 1$, an epidemic is certain in a deterministic model and has nonzero probability in a stochastic model. Strategies for disease control and eradication are aimed at bringing R_0 below the threshold of unity, which implies that each new infection, on average, generates fewer secondary infections than is necessary for sustaining the epidemic. However, because HIV is transmitted by intimate sexual contact between partners and because people employ potentially complex rules to select their sexual partners (Watkins 2004; Magruder 2008), HIV transmission dynamics in real populations are not well described by the classical epidemiological model. In other terms, $\bar{c}$ is generally a poor approximation of the patterns of contact leading to the diffusion of an infection within a population. For instance, *small worlds* (networks characterized by bridges joining otherwise disjoint clusters) can lead to thresholds and rapid disease diffusion to distant subpopulations (Watts and Strogatz 1998; Watts 1999); *skewed degree distributions* (networks containing individuals with a relatively very high number of partners), can result in epidemics driven by promiscuous individuals (Liljeros et al. 2001; for a critical perspective, see Jones and Handcock 2003b; Handcock and Jones 2004). While sophisticated analytic methods have recently become available that allow investigations of networks that deviated from the assumptions of the classical epidemiological model (Koehly, Goodreau, and Morris 2004), their application to context of high HIV-prevalence in SSA has been hampered by a lack of suitable data on the rate of contact between susceptible and infectious individuals ($\bar{c}$).

3. Practical challenges facing network studies

The collection of large-scale data on sexual networks, which can provide information about $\bar{c}$, is a challenging undertaking facing abundant practical obstacles (Morris 2004; Doherty et al. 2005).

3.1 Potential sources of bias in network tracing

Doherty et al. (2005) identifies three difficulties that may lead to *incomplete-network bias*: "the incomplete ascertainment of sociometric networks is inevitable in both clinical and research settings, because (1) people may be reluctant to name all sex partners [...]; (2) they may be unable or unwilling to provide adequate contact information for locating partners; or (3) partners may be locatable but difficult to reach."

The first aspect, the misreporting of sexual partners and sexual relationships, is pervasive in all inquiries of sexual behaviors (Cleland et al. 2004), including large-scale individual centered surveys such as the Demographic and Health Surveys (DHS). The second and third aspects (insufficient information for partner tracing and failures to locate nominated partners), on the other hand, are specific to sociocentric studies of sexual networks. In developed countries, data on sexual networks are frequently collected within healthcare settings during contact tracing interviews of STI cases (Klovdahl et al. 1994; Wylie, Cabral, and Jolly 2005; Ghani et al. 1996). Such data have provided seminal insight on the role of sexual network structures in shaping disease diffusion among high-risk groups. Contact tracing procedures involve collecting and managing extensive identifying information on partners of infected individuals, including information such as names, address, phone number, and various sociodemographic characteristics. Even in resource-rich contexts, the collection and management of such information can be very cumbersome, and it is often the case that the information provided by respondents during contact tracing interviews is not accurate, or is not detailed enough to eventually find the nominated partner (Potterat et al. 2004). As a result, a large proportion of contacts are never traced during sociocentric studies (Potterat et al. 1999; Koumans et al. 2001; Ghani et al. 1996) and the descriptions of the networks produced during similar inquiries are partial. These difficulties of contact tracing appear compounded even further in SSA, because individuals are not easily identified. For example, often there are no street names, house numbers, and/or phone numbers where contacts can be reached. It may also happen that someone uses different names or nicknames under various circumstances or changes names after important events of the life cycle (e.g., sexual initiation among certain ethnic groups), making identification and contact tracing problematic.

The problems of locating nominated partners are also akin to a *boundary specification problem* (Laumann, Marsden, and Prensky 1983). In the study of diffusion processes, it

is not clear where to draw the line between members and nonmembers of a population. Influential individuals may well reside outside of a specific area or may not belong to a group defined by a certain criteria. In a reanalysis of the classic study of the adoption of the drug Tetracycline among a network of medical practitioners in Illinois for example (Burt 1987; Coleman, Katz, and Menzel 1966), Van Den Bulte and Lilien (2001) show that marketing agents were the most influential proponents of the drug. However, the network data collected by Coleman and others (Coleman, Katz, and Menzel 1966), did not include such actors within its boundaries. In the case of HIV spread, groups of "outsiders" such as truck drivers, people from town, etc., have been identified as playing a disproportionate role within sexual networks transmitting HIV in rural areas of SSA (Hudson 1996; Caldwell, Caldwell, and Quiggin 1989). Such groups represent epidemiologically important *bridge populations* (Lurie et al. 2003; Lagarde et al. 2003; Caldwell, Caldwell, and Quiggin 1989) who may continually reintroduce HIV within rural villages. Because these important populations reside outside of local communities and/or are highly mobile, they are challenging to reach and are likely to be systematically underrepresented in sexual network studies.

3.2 Likoma Island as an "epidemiological laboratory"

Some network studies have attempted to limit the time spent on contact tracing by implementing various selection schemes to enroll only a subset of the contacts named during tracing interviews. Various sampling schemes based on snowball sampling and the statistical random walk theory have been suggested (Klovdahl 1989). Unfortunately, the properties of network estimates derived from such data are not fully understood. An alternative approach has recently been developed in which researchers ask study participants to enroll their (sexual) contacts. This sampling technique is referred to as "respondent-driven sampling," and its statistical foundations have been investigated in detail (Salganik and Heckathorn 2004). However, such a method is highly vulnerable to respondents' willingness to divulge intimate details, especially if (financial) incentives are associated with participation in the study. Other studies of complete networks have addressed the above challenges by carefully selecting study populations that have well-defined boundaries as well as a limited size that allows efficient identification of network members. For example, the classic dataset of a complete network describes friendship connections between monks of a monastery (Sampson 1969), and an important study of sexual networks among adolescents focused on students in a mid-western U.S. high school (Bearman, Moody, and Stovel 2004). Most of the other sociocentric network projects focus on small groups within organizations (Krackhardt 1987), small groups of families (Padgett and Ansell 1993), or other well-delineated small populations.

Following this tradition of studying networks in well-defined populations, the LNS aimed at tracing the sexual networks of young adults on Likoma Island in Malawi. Likoma Island is located in the northern region of Lake Malawi (Figure 1), extends over only 18 square kilometers, has limited transportation to the mainland, and its population is small with just over 7,000 persons living in a dozen villages (Section 5.1). As a result, a limited set of identifying information allows tracing contacts nominated during a sociocentric network study.

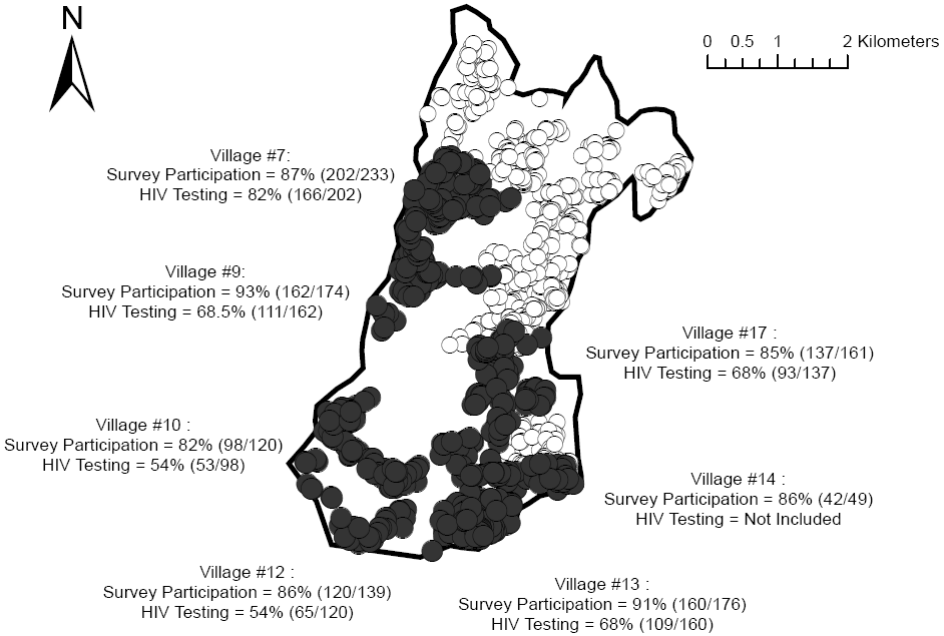
The choice of an island as research site for the LNS also follows a long tradition of island studies in epidemiology and biology (Whittaker 1999; Cliff, Haggett, and Smallman-Raynor 2000). Researchers have been able to use islands to study and identify the mechanisms through which an infection diffuses locally through a population as diseases are less likely, than on the mainland, to be continuously re-introduced through migration or travel. For example, analyses of flu or measles epidemics in Iceland and the Pacific Islands have contributed greatly to our understanding of the spread of airborne diseases. This advantage of island studies also pertains to the study of HIV, where many epidemiological studies have emphasized the role of migration and mobility in the spread of HIV (Glynn et al. 2001b; Coffee et al. 2005; Lurie et al. 2003).

4. Data collection procedures in the Likoma Network Study

In this section we describe the data collection procedures that were implemented as part of the LNS to try and reconstruct the sexual networks connecting the inhabitants of the study villages chosen for this project (Figure 2). The protocol for this study was approved by institutional review boards at the Malawi College of Medicine and the University of Pennsylvania. Community approval was obtained during meetings with local representatives (traditional chiefs, district representatives), and informed consent from the study participants was obtained prior to interviews and HIV testing.

The data collection of the LNS took place between October 2005 and March 2006 and involved three different phases. The *first* phase consisted of a census of all households on Likoma Island, with the aim to establish a roster of all current and recent Likoma residents who could have been potential local members of sexual networks on Likoma. The *second* phase consisted of an in-depth sexual network and health survey among all young adults aged 18–35, which was conducted in a subset of the villages of Likoma Island. Finally, the *third* phase involved the collection of biomarkers for HIV infection among respondents to the network survey.

Figure 2: Geographic location of the sampled villages and village-specific participation rates



Each circle represents a dwelling unit. Dark circles represent housing units that were included in the sexual network survey. Empty circles represent housing units that were not included in this sampling frame. Denominators of the survey participation rates are the total number of eligible respondents (aged 18–35 and their spouses) in a given village, based on the initial household census. Denominators of the HIV testing participation rates are the total number of respondents who completed the sexual network survey in a given village. Island boundaries and location of dwelling units are approximate.

4.1 Rosters of potential network partners

a) Household rosters: Extensive information about the socioeconomic characteristics of each household (e.g., housing type) on the island, as well as the names, maiden names (for married women), potential nicknames, ages, and marital histories of all residents of a household were collected using household rosters in the first phase of the LNS. Each house on the island was visited be an interviewer, and after receiving a brief introduction to the LNS, available informants in each household were asked to answer questions about the household and all household members. The eligibility criteria for informants

included being older than 18 years old, and being a regular member of the household. The LNS household census also included vacated dwellings: neighbors of empty houses were asked to answer a one-page questionnaire about former residents of the house. The vacated dwellings questionnaire included questions about family name, former head of the household, time since the house had been vacated, and reason for departure.

b) Migration and mortality: Because migrants and recently deceased individuals have been identified as crucial for disease spread (Lurie et al. 2003; Wawer et al. 2005; Coffee et al. 2005; Coffee, Lurie, and Garnett 2007), household informants were asked about *(i)* temporary migrants from their households, *(ii)* household or extended family members who moved permanently out of Likoma over the last five years, and *(iii)* household or extended family members who died over the last five years. For each of these, the informant was asked to provide names, potential nicknames and sociodemographic characteristics (age, sex, education, marital status, etc.). For migrants, the date of departure, the reason for departure as well as the destination were noted. For the deceased, the date of death as well as a few questions relating to the cause of death and probable final illness were collected. The lists gathered through the household census and migration/mortality modules constitute additional rosters of potential social and sexual network partners that we use to link records of relationships (see below).

c) GPS data: During the household listing, we collected the GPS coordinates of all the dwelling units we visited. We tracked the main roads and pathways people use to travel around the islands. Finally we referenced the main landmarks and public places in each village: for example, each school, church, well, or village center were located. This information is extensively used to identify sexual partnerships (see below).

4.2 ACASI network survey

d) Study populations: Seven adjacent villages on Likoma Island were sampled for the sexual network survey (Figure 2) that collected extensive data about the sexual partnerships of young adults on the island. The selection of these seven villages was purposive: we initially selected two "seed" villages in which the proportion of births out-of-wedlock reported during the household listing was significantly higher than in the other villages. We interpreted this difference as indicating either a higher prevalence of extra-marital relationships in these villages or a higher propensity to report such relations during a survey. These two villages were located on opposite sides of the island, and showed largely different village contexts: in one village, fishing is the quasi-exclusive source of income, and as a result most males spend their days (and often nights) on the lake. Women, on the other hand, often travel to the local trading center (or to the mainland) to sell their husbands' and siblings' catches. There is very little "village life" as no groceries nor bottle stores are located within the village. In contrast families in the other seed village have

stronger ties to the mainland of Malawi, and remittances represent a significant source of income for many households. As a result, fishing is not the focus of social and economic life, and on most days large groups of people can be found gathering close to the grocery stores or at the village center, playing games of bawo (a local board game), chatting and, for men, drinking beer. Geographically, the sample thus stretches from the southern tip of the island to the northern shores of Likoma.

In the sampled villages, we interviewed *all inhabitants aged 18–35 and their older spouses*. We limited our sample to this age group, because (1) it represents the age range during which most incident HIV infections occur (e.g Heuveline 2003), and (2) it represents the age range during which most nonmarital sexual networking seems to take place (Nnko et al. 2004; Glynn et al. 2001a). This limitation of the sample to the younger age groups generated some confusion among the population, especially because we explained the purpose of our study as trying to identify the factors affecting the spread of HIV. Older respondents argued (rightly so) that they were also at risk of acquiring HIV and as such should have been interviewed by the survey team (and especially tested during the collection of biomarker data).

Prior to the start of the study, we conducted a pilot of the interviewing software in two separate nonsample villages of Likoma. We chose these two villages for their convenience as they were immediately bordering the trading center where the research team was staying. In the first village, we interviewed 20 respondents using an initial version of the sexual network interviewing software. After getting feedback from both interviewers and respondents during this pilot, we realized that our initial strategy to identify sexual network partners was unlikely to be successful (see Section h). We thus significantly revised our interviewing strategy (see below) and conducted a second, more extensive pilot with roughly 80 respondents and updated interviewing software. This second pilot proved largely successful and initial releases of the network data included relationships identified from pilot interviews. But, because interviews were conducted with only 60% of village inhabitants (a response rate significantly lower than in the other sample villages and one that does not allow drawing a quasi-complete picture of the village network), these data are discarded from the final analyzes. In addition, the final version of the software used during fieldwork is slightly different from the version we used during this pilot.

e) Length of the recall period: During surveys of sensitive practices (e.g., drug injections, commercial sex...), respondents are usually asked to recall their behaviors over short periods of time. Bell, Montoya, and Atkinson (2000) for example uses a recall period of 30 days. In the case of HIV transmission though the period of infectivity can last for years, hence asking questions about such short periods is likely to omit most of the behaviors and partnerships that may have led to infection. Instead, we chose a recall period of three years that likely encompasses a significant proportion of the partnerships during which HIV was transmitted in a population aged 18–35. Such a long recall period, how-

ever, prone to cause informants to forget partners (Brewer and Webster 1999). To reduce this effect of partial recall in the construction of the population-level network, a sexual relationship was assumed to have taken place between two partners if it was reported by at least one partner.

f) Fixed choice design: As we argued above (Section 2), the variance of the degree distribution is an important parameter in mathematical models of STI spread. Unfortunately, the behaviors of highly active network members are often difficult to measure in empirical studies. For example, highly sexually active survey respondents may grossly misestimate the number of their partnerships (Handcock and Jones 2004). Several studies have also shown that respondent's fatigue builds up quickly in network surveys (White and Watkins 2000), and respondents become bored with answering the same set of questions about a (possibly large) number of different partners. As a result (and also because of software and programming constraints), we followed a common practice in network research and imposed a cutoff on the number of partnerships to be reported. This value was set at five. Such a research design may lead to bias in estimates of network properties (Kossinets 2006; Costenbader and Valente 2003) if it is close or even below the mean of the underlying degree distribution. However, if the mean of the underlying degree distribution is well below the cutoff used during a network survey, then various structural properties (e.g., dyad or triad census) of the underlying networks are less affected by missing data (Wasserman and Faust 1994, Chap. 13). We estimate in Section 5.3.1 the proportion of respondents who might have reported more sexual partnerships if such a fixed choice design had not been used.

g) Definition of sexual partner: The goal of the sexual network survey was to elicit sexual relationships of the respondents during the three years prior to the survey, including regular and stable relationships (with the spouse or a regular extramarital partner) as well as relationships that were short-term and/or infrequent (a one-off relationship, a sexual encounter with a visitor, etc.), or relationships that occurred during the marriage process as part of dating and partner search. The local language, *Chichewa*, has a specific term to designate sexual partners: "chibwenzi." This expression translates loosely as "someone who provides for one's sexual needs," and this is the term that was used throughout the survey to signify a sexual partner. The term "chibwenzi" does not subsume relationships with prostitutes. Using the Chichewa term "chibwenzi" during the sexual network survey, therefore, captures all types of the sexual relationships between members of the general population but may nevertheless leave out some relationships between members of these populations and some members of core groups (e.g., sex workers).

h) Strategy for identifying sexual partners: Tracing sexual networks during empirical studies generally involves looking up names generated during a survey and comparing them to preexisting rosters of potential network partners. While previous studies of sexual networks having used ACASI technology (Bearman, Moody, and Stovel 2004) put this burden on respondents and asked them to directly browse through rosters of potential partners, this was found to be highly impractical in Likoma, where computer literacy is minimal. Indeed, during pilots and pretests, we experimented by inputting the rosters created from the household census into audio files and incorporating them in our interviewing software, so that respondents themselves could establish links. But pilot respondents were surprised (and at times angered) that a machine could know the names of actual people. Furthermore, the thousands of audio-files (*.wav files) required to enable this interviewing strategy were significantly slowing down the ACASI software.

Thus we developed an alternative linking strategy. Respondents were asked to mention the name of each of their partners through recording headsets. For the purpose of identifying sexual partners in the rosters of potential partners, they were asked where the partner they mentioned was currently residing and where he/she was residing at the time of the relationship (if the relationship was over). If the partner ever resided on Likoma, they were asked to provide additional details about his/her residence, i.e., in which village and where specifically in this village this person was staying. For example, from such information we know that a respondent has been involved in a relationship with "John Banda" who lives in Ulisa village close to the grocery store, etc. A few questions on the socioeconomic characteristics (e.g., daily activities, age, etc.) of the partners were asked to help narrow down the list of potential matches. If the partner had never resided on Likoma, respondents were only asked to mention the first name or the initials of their partners, and the audio-files were subsequently discarded. This name-generating process was repeated by the software for up to five partners. Stored audio files (i.e., including full names of partners who had ever resided on Likoma) were downloaded daily by the data management staff and linkages with the village/migration rosters of potential network partners were generally conducted and checked within two days of the interview. These checks were initially conducted using phonetic name-matching routines (Blasnick 2001), and finalized through manual inspection of the village and migration rosters by the investigator present in Likoma during fieldwork. Through this process, we are able to reconstruct networks of sexual relations within which inhabitants of these villages are embedded.

It is important to note that this linkage strategy involves absolutely no "active" contact tracing, during which the researcher approaches the partner(s) of initial cases using the information gathered during interviews. Contacting a nominated partner as part of the survey would signal to other community members (including spouse and family members) that a person belongs to an extended network of (possibly extramarital) sexual relations in a tightly knit rural/island setting. Our approach on the other hand is inclusive as *respondents are only approached by the research team on the basis of their residence and their age*.

4.3 Relationship and health data

In addition to questions allowing the identification of sexual partners, respondents were asked a short series of relationship-specific questions during the ACASI interview. These questions related to the initial meeting and conditions that surrounded the initiation of the relationship, including how the two partners knew each other before the start of the relationship, where and when the first meeting occurred, when the relationship ended and what caused the relationship to end. Additional questions related to sexual activity within the relationships, including whether or not the relationship involved sexual intercourse, the frequency of sexual intercourse within the relationship, and whether condoms were used during sexual intercourse. The final series of questions related to respondents' perceptions of HIV/STD risk at the time of the relationship.

After completion of the sexual networks part of the ACASI interview, respondents were asked to answer questions regarding their own health, including: a self-reported assessment of general health; the presence and frequency of specific symptoms such as headache, stomach ache, general weakness, joint aches, painful urination or discharge during urination, ulcers in the genital area; the use of healthcare when these symptoms occur; previous use of HIV testing services, and reasons for not being tested (e.g., distance, cost, stigma associated with testing centers). Additionally, a history of injections received during healthcare, as well as the date, location and the reason for the last injection received by the respondent were incorporated into the assessment.

4.4 HIV testing

After the completion of survey fieldwork, which lasted a month, each respondent was revisited by a member of the research team and was offered a free HIV test. The research team for this phase of data collection was composed of one nurse in charge of the overall supervision of biomarker collection, and ten health counselors trained by the Malawian ministry of Health. This team of health counselors visited all respondents in six of the seven survey villages (see also Figure 2). The 7^{th} village—village 14 in Figure

2—could not be included due to funding and timing constraints limiting the scope and duration of the fieldwork. As a result, this village is included only in analyses of sexual network structures, but is excluded from all analyses relating to HIV risk factors. When approached by the health counselors, respondents were offered the opportunity to receive HIV counseling and testing in their homes using rapid HIV tests. Because individuals might be concerned about the privacy of in-home HIV tests, respondents were also given the option to be tested at another location (i.e., the team's hotel). The rapid HIV tests were conducted using a parallel testing algorithm approved by WHO (World Health Organization 2002) and the Malawian Ministry of Health. Two rapid HIV tests, Unigold (Trinity Biotech, Ireland) and Determine (Abbott, Japan) were run simultaneously at the respondent's home. Blood samples that were concordantly negative or positive were considered to be a true result. Four discordant results were obtained and were referred to local testing centers for confirmatory testing after a few weeks. Results were available to the respondents after 20 minutes, but respondents were also given the option to retrieve their test results at a latter date if they so desired.

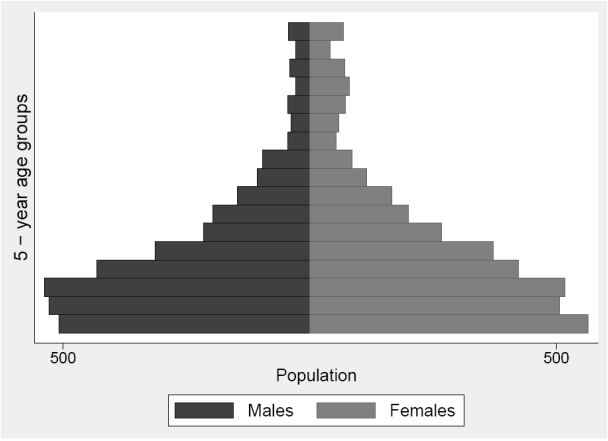
5. Results

5.1 Study context: Household listing data

In this section, we use data from the household census to provide background information on the composition and socioeconomic conditions of the island. In total 1,235 households participated in the household listing stage of this study. In 85% of cases household informants were either the household head or his/her spouse. These data indicate that the population of the island was a little above 7,000 people living in a dozen villages ($N = 7,015$) at the time of the household listing. The average size of a household was 5.7 members (IQR = 4–7). Of all the household members listed during the household census, 8.4% had not slept at their homes the night prior to the listing team's visit. For adults ages 18–59, men were more than twice as likely as women to have slept away from their homes the night prior to the listing team's visit (7.8% vs. 15.6%, $p < 0.01$). Most houses on the island were composed of three rooms (mean = 3.16, IQR = 3–4). The population of the island was extremely young, with 47% of men and 39.5% of women under 15 years old (Figure 3). The sex ratio for the population as a whole was 1.11, but the excess of women was more pronounced at adult ages: between the ages 20 to 24, there were 1.18 females per male in the population, and between the ages 25 to 29, there were 1.24 females per male. These imbalanced sex ratios might be attributed to migration of young men to look for employment or to further their schooling, as well as differential mortality due to accidents (fishing) and HIV-related illnesses. Comparison with Census data (projections for 2005, NSO 2004) show that the imbalance of sex ratios is only slightly more pronounced

on Likoma than in the rest of rural Malawi, where out-migration of young adult males to the larger cities of Lilongwe, Blantyre and Mzuzu (Figure1), or abroad is also quite frequent.

Figure 3: Age and sex distribution of all inhabitants residing on Likoma Island. *De Jure* population as of November 2005



Source: Likoma Network Study Household Listing

The population of Likoma was comprised primarily of the Nyanja and Tonga ethnic groups (75% of Likoma inhabitants are Nyanja by tribe, 10% are Chewa, 10% are Tonga, and the remaining 5% belong to diverse ethnic groups present in mainland Malawi or Tanzania such as Tumbuka, Swahilis, Yaos, Chewas, etc.). The Tongas of Likoma were mostly found in two villages of the island located on the southern shores, whereas the other (i.e., nonNyanjas) ethnic groups resided mostly around the trading center. The overall level of economic development of the island was low, with fishing the main source of income for most households. Transportation to Likoma is limited, as there is only one boat a week to mainland Malawi, although a few small canoes make daily trips to the Mozambican shore. Despite these constraints, inhabitants of the island traveled frequently: two-thirds of males and more than half of females had gone to mainland Malawi in the year prior to the survey, while almost half of males and one-third of females had gone to Mozambique over that same time span. Our data does not allow estimating the duration of the various trips to the mainland, but casual observation suggests that time spent off of the island varies greatly with the purpose of the trip. Business trips to sell fish in mainland Malawi or to collect firewood in Mozambique take a few days at the most.

Trips to visit relatives and/or to get medical treatment may last much longer. On average, men between the ages 18–59 have completed 8.1 years of schooling, while women in the same age range have completed 7.2 years ($p < 0.01$). 46.3% of men in this age range had completed primary schooling in 2005 (8 years of formal schooling), but this was the case for only one-third of women. Five percent of the adult island inhabitants had never attended school, and this proportion did not differ by gender.

5.2 Patterns of participation and nonresponse

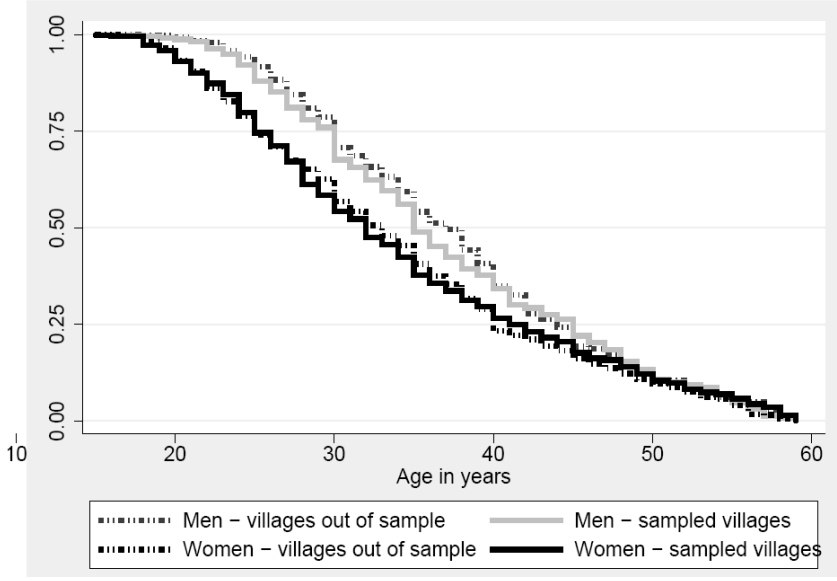
Seventeen households refused to be interviewed during the initial stage of this study, and we do not know how many individuals were members of these households. We selected 7 of the 12 villages for inclusion in the sexual network study (Figure 2), representing 50.9% of the total adult population aged 18–35 of Likoma. Men in villages not included in the sample had on average one more year of schooling than men in sample villages ($p < 0.001$). Women in nonsample villages were also more educated than women in sample villages by an average of nine months ($p < 0.001$). This is likely the case because administrative services and NGOs operating on the island (who employ individuals with a high school certificate and often some college education) were located at the trading centre (a larger village called "Mbamba"). This trading centre was not part of the LNS sample. In addition, sampled households were slightly larger than nonsampled households (5.8 vs. 5.1, $p = 0.03$). Inhabitants of sampled villages, however, were not more likely to have ever been married than out-of-sample inhabitants suggesting that patterns of sexual networking, may be relatively similar in sampled and nonsampled villages (Figure 4).

A total of 923 inhabitants in the sampled villages were interviewed during the sexual network survey (422 Males and 501 Females), and the participation rate was 88% (923 participants out of 1,052 eligible respondents). The main reason for nonparticipation in the survey was temporary migration to the mainland of Malawi or Mozambique. Very few potential respondents refused to participate in the survey ($N = 21$, 2.5%). Response rates by village are displayed in Figure 2. Participation rates ranged from 82% to 93%, but did not differ significantly by village nor by gender. Eligible respondents who refused to participate in the study did not differ from study participants on most socioeconomic characteristics. However, men who did not participate in the survey were generally more educated than men who participated (8.2 years of schooling vs. 7.6 years, $p = 0.09$).

Among the respondents who agreed to participate in the LNS, very few respondents refused to complete the computer-assisted section of the survey after having completed the face-to-face interview. Only four respondents refused to complete the computer-assisted part of the interview, and three others could not complete the ACASI interview: one was deaf; the two others were epileptic and were greatly concerned that listening to questions through headsets would set off an epileptic attack. Similarly, even though respondents had

the possibility to skip or refuse to answer every question of the audio-survey by a simple touch on the computer's touchpad, few refused to name partners or to answer questions concerning partners' residence. Such refusals usually came after two or three partners had already been named, and might indicate an inadvertent error from the respondent or fatigue. Comparatively, refusal rates for single items were significantly higher for questions about occasions of initial meeting (10% missing data), or questions relating to condom use. We suspect, however, that when a respondent wanted to keep a relationship secret, he/she used names such as "Andreya Banda" or "Esther Phiri" for their partners, which are the equivalent of "John Doe" or "Jane Doe" in the U.S. We generally had difficulties linking such common names to our village/migration rosters.

Figure 4: Kaplan-Meier estimates of age at first marriage among inhabitants of Likoma Island



Note: De Jure population as of November 2005;
Source: Likoma Network Study Household Listing

5.3 Sexual partnerships: descriptive statistics

5.3.1 Outdegree distributions

The outdegree of a respondent is the number of partners that were nominated by a respondent during the sexual network survey. Males reported having been involved in a total of 2.41 relationships per respondent (Figure 5a) during the three years prior to the survey, whereas women reported a total of 1.82 relationships over the same time span ($p < 0.01$). Only 2% of women and 8.4% of men reported five partnerships, implying that they were potentially involved in more relations but were not allowed to report more by the interviewing software. The variance of the outdegree distribution was significantly lower than its mean (0.92 for women, 1.3 for men), but this is likely due to the fact that the outdegree distribution was truncated at five. A little over 5% of respondents reported no sexual partnerships during this survey, and among these the proportion of males was slightly higher (Figure 5a). When the period of observation is restricted to the year prior to the survey (Figure 5b), more respondents report not having been involved in a relationship (10%) and the majority of respondents report only one partnership. 28% of women and 43% of men nevertheless report more than one partnership ($p < 0.01$) during the year prior to the survey.

Figure 5: Outdegree distributions among survey respondents, by gender

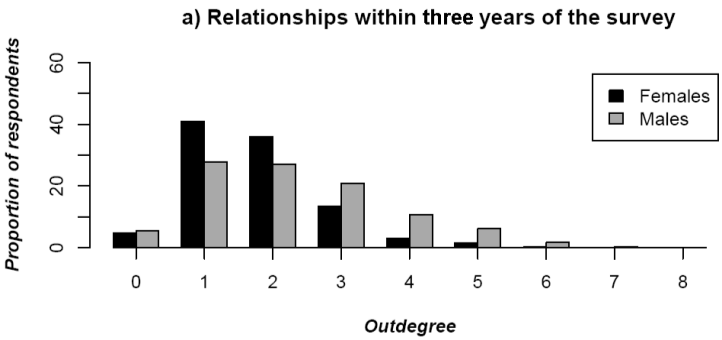
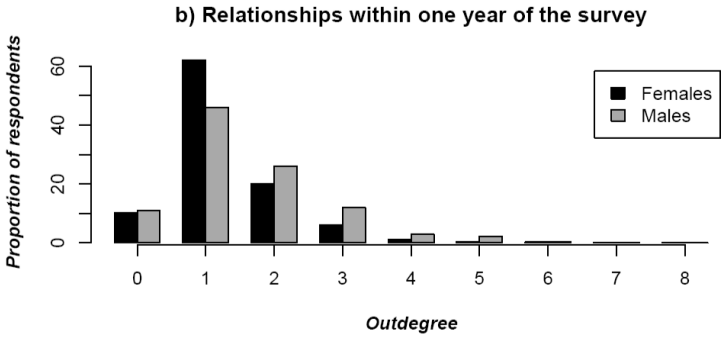


Figure 5: (Continued)



5.3.2 Characteristics of sexual relations reported during the network survey

Following from the distribution of outdegrees, a total of 2,040 reports of relationships were collected from the 923 respondents during ACASI interviews. Among those, 1,858 were said to have involved sexual intercourse (or 91%). Table 1 describes characteristics of the reports of sexual partnerships made during the network survey, and Figure 6 summarizes the steps involved in the linking process and the terminology we use in our analyzes.

Table 1 shows that 30% of the relationship reported by women were marital relationships, whereas marital relationships constituted only 20% of men's reports. The majority of relationship reports collected during this survey were thus described by respondents as nonmarital relations. One-off-encounters ("one-night-stands") represented only 7% of all reports, and infrequent partners accounted for slightly over 20% of all nominations. As a result, relationships included in the network are relatively stable. Nominations of partners residing on Likoma at the time of the survey accounted for 70% of all reports, a relatively high percentage compared to Bearman et al.'s (2004) study of a secluded US high school, where only half of the nominations were to fellow students. There were significant differences in the residence of sexual partners by type of relationship: most marital partners co-resided on Likoma, but a significant proportion of nonmarital sexual relationship took place in nonsampled villages on the island, or *off the island*. Only two-thirds of steady and infrequent extramarital partnerships took place between current residents of the island, and this proportion decreased even further in the case of one-night stands (50%, see Table 1). There were also significant gender differences in patterns of geographical mix-

ing: most nonmarital partnerships of women either took place with other inhabitants of Likoma or with partners residing on mainland Malawi. Men, on the other hand, engaged in nonmarital partnerships with partners from more diverse contexts, for example with residents of a neighboring island (Chizumulu) or with residents of Mozambique. This pattern of sexual mixing seems to reflect daily patterns of mobility (see Section 5.1). In addition, 11.3% of women, but only 3.5% of men reported a marital partner outside of Likoma. Spousal separation was often due to divorce (the relations in Table 1 include some relationships that were over at the time of the survey), but may also have occurred because of migration of one of the spouses (generally the man). Finally, women were more likely to report having been involved in a sexual relation with someone who had since died. The proportion of deceased partners was significantly higher in short and unstable partnerships.

Figure 6: Flow chart of the linking process and terminology used

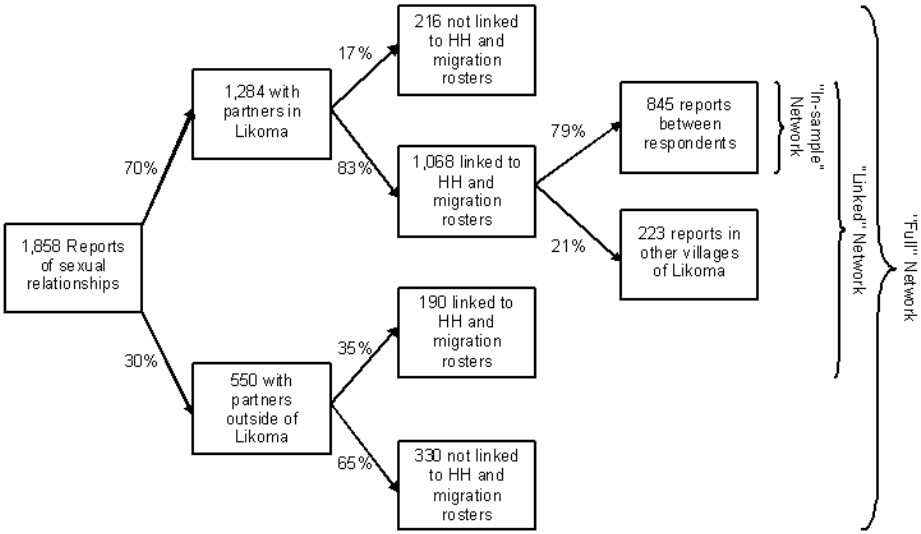


Table 1: Characteristics of relationships reported during the sexual network survey

	Relations reported by women			
	Marriage	Steady partner	Infrequent partner	One-night stand
	$N = 272$	$N = 344$	$N = 200$	$N = 51$
Proportion of partners who were currently residing				
in Likoma	83.5	61.3	64.6	52.1
in Chizumulu	1.1	2.7	6.2	4.2
in Mozambique	1.8	4.0	2.1	2.1
in Malawi	11.3	26.1	21.4	22.9
Proportion of partners who were dead	4.1	4.0	5.2	14.6
Proportion of traced partnerships				
if partner currently resides in Likoma	95.5	76.3	79.0	68.0
if partner currently resides off Likoma*	75.0	57.9	60.0	51.4
Proportion of in-sample partners				
among partners currently in Likoma	71.9	50.9	52.4	52.0
jointly reported **	94.0	52.4	27.5	31.2
	Relations reported by men			
	Marriage	Steady partner	Infrequent partner	One-night stand
	$N = 200$	$N = 401$	$N = 247$	$N = 88$
Proportion of partners who were currently residing				
in Likoma	92.5	66.9	64.2	50.6
in Chizumulu	0.0	5.0	8.2	6.0
in Mozambique	2.5	4.1	4.7	9.6
in Malawi	3.5	19.4	15.9	19.3
Proportion of partners who were dead	1.5	1.5	3.0	13.2
Proportion of traced partnerships				
if partner currently resides in Likoma	95.1	81.1	71.8	78.6
if partner currently resides off Likoma*	60.0	62.0	45.4	45.0
Proportion of in-sample partners				
among partners currently in Likoma	85.9	58.0	50.3	52.4
jointly reported**	96.9	35.0	20.0	10.4

Notes: Reported numbers in the table are percentages (except for p-values). p-values are based on chi-square tests of associations. * Among partners who have ever resided in Likoma. ** among in-sample partnerships

Table 2 provides further descriptions of the context and characteristics of nonmarital relationships reported during the sexual network survey. Several characteristics of relationships differed significantly between gender and across relation type. Whereas most relationships (almost 70%) were initiated on the island, men were much more likely to engage in one-off encounters outside of Likoma. Almost half of the one-night stands reported by men took place either in Mozambique, Chizumulu, mainland Malawi or possibly elsewhere (e.g., Tanzania, South Africa). The large majority of partnerships are with someone the respondent was acquainted with prior to starting the relationship. The occasions and specific contexts during which men and women meet different types of partners also varied quite widely. Men were more likely to meet their short-term partners during business trips or while traveling to the mainland on a steamer. Religious gatherings contributed to the formation of more than 10% of partnerships, but women in particular report that very few unstable partnerships were formed during such events. School and traditional events (Mganda) represented the two settings during which most partnerships were initiated. Further differences were found with respect to the type of relationship that existed between partners prior to the initiation of the sexual partnership. 25% of nonmarital sexual partnerships were initiated between partners who did not know each other or had just met. Men were slightly more likely to engage in partnerships with women they did not know, and these partnerships often led to "one-night stands" or unstable relationships. Less than 10% of extramarital relationships took place with a relative, but close to 23% of the one-night stands reported by women were with someone they were related to (either by blood or by marriage, i.e., in-laws).

Reported starting times of relationships differed greatly across types of relationships: over 60% of all extramarital relationships reported during the sexual network survey had started more than a year prior to data collection, but this proportion was significantly higher among the steady relationships. In particular, more than 20% of the one-night-stands reported by women had occurred during the month immediately preceding the survey, while only 6% of their more stable relationships began within one month of the survey. Similarly, almost half of the one-night stands reported by men occurred during the year prior to the survey. Relationships classified as "steady partnerships" were reported—as is expected—to last longer than other types of extramarital relationships. A small proportion of one-night stands having started more than a year prior to the survey were still ongoing at the time of the survey, suggesting possible misclassification of these partnerships.

Table 2: Characteristics of nonmarital relationships reported during the sexual network survey

	Relations reported by women		
	Steady partner	Infrequent partner	One-night stand
Context of initial meeting			
Place of first meeting			
In Likoma	75.8	77.0	62.5
Occasion of first meeting			
In school	43.4	38.1	42.2
Mganda dances	23.5	31.2	22.2
During business trip	8.8	7.7	15.6
On the steamer	6.2	7.7	8.9
At a religious meeting	13.7	13.8	5.1
Type of relation			
Did not know each other	21.3	23.4	14.6
Relatives	5.8	6.2	23.2
Friends	36.8	30.7	31.2
Acquaintances	33.7	38.5	29.1
Timing & duration of relationships			
Started w/in last month	6.2	6.7	20.8
Still ongoing	65.2	38.4	40.0
Started w/in last year	24.4	33.9	14.6
Still ongoing	55.5	23.1	0.0
Started more than a year ago	68.3	59.4	64.6
Still ongoing	30.6	7.9	3.1
Frequency of encounter			
Weekly or more frequent	52.7	51.9	50.0
Condom use			
Never	34.4	36.2	45.8
Sometimes	41.2	38.8	37.5
Always	24.3	25.0	16.7
HIV risk perception			
Worried a lot	12.8	23.3	22.9
Worried a little	30.1	22.7	20.8
Not worried at all	54.1	52.9	54.1
N	344	200	51

Table 2: (Continued)

	Relations reported by men		
	Steady partner	Infrequent partner	One-night stand
Context of initial meeting			
Place of first meeting			
In Likoma	74.5	74.0	51.8
Occasion of first meeting			
In school	37.0	31.4	32.9
Mganda dances	28.8	29.5	20.2
During business trip	8.1	10.0	20.2
On the steamer	9.0	15.4	13.9
At a religious meeting	11.4	10.9	12.6
Type of relation			
Did not know each other	19.4	25.9	37.8
Relatives	7.2	9.5	12.2
Friends	34.6	26.7	14.6
Acquaintances	36.2	36.6	32.9
Timing & duration of relationships			
Started w/in last month	6.3	5.6	10.8
Still ongoing	51.7	15.4	22.2
Started w/in last year	27.0	29.3	37.4
Still ongoing	56.4	19.1	6.1
Started more than a year ago	65.1	65.1	51.8
Still ongoing	22.4	7.9	4.6
Frequency of encounter			
Weekly or more frequent	67.0	57.5	55.4
Condom use			
Never	32.8	33.2	33.7
Sometimes	36.0	41.0	37.3
Always	31.2	25.7	28.9
HIV risk perception			
Worried a lot	13.7	14.4	22.9
Worried a little	23.4	28.4	31.3
Not worried at all	60.5	55.9	42.2
N	401	247	88

Notes: Reported numbers in the table are percentages.

With respect to relationship-specific risk factors for HIV infection, male respondents reported significantly more frequent sexual activity within all types of relationships than

women. This pattern was especially apparent in steady relationships. Consistent condom use was reported in 25–30% of all extramarital relationships, in general to prevent infection with STDs. Finally, levels of worry about HIV were lower in more stable relationships.

5.3.3 Patterns of partner tracing

Of the sexual relationships involving two partners currently residing on Likoma ($N = 1,284$), we were able to trace both partners within our lists in 84.9% of the cases (80.5% of extramarital relationships and 94% of marriages). Tracing rates of partners residing within the island did not differ systematically by gender, but less stable relationships were notably less likely to be linked to a record in the village rosters. This differential success in tracing partners potentially introduces a bias of our network data towards more stable/legitimate relationships, but we are unable to measure the extent of this bias at this point.

When the nominated partner is not currently residing on the island or has died (but was residing on the island at the time of the relationship, $N = 303$), on the other hand, we are able to trace him/her within our rosters of migrants from the island in 62.5% of the cases. This lower tracing rate may suggest that *(i)* migrations or deaths were underreported during the migration/mortality module, *(ii)* the timing of migration and/or death may have been misreported during the migration/mortality module.

Table 3 compares the relationship characteristics between relationships that we could and could not successfully trace in the LNS household rosters (Section 4.1. Relationships that were not traced were slightly more likely to involve two partners who had met off of the island, and nontraced partnerships were more likely to involve two partners who did not know each other prior to the start of the relationship. This may be the case because such partners only have limited information about each other, and may thus not be able to provide accurate "tracing" information. More than 40% of the nontraced partnerships of women were with partners they were friends with prior to the start of the relationship, and the occasions during which traced and nontraced partnerships were initiated did not differ significantly. However, the timing and duration of nonmarital relationships had a dramatic impact on our ability to trace nominated partners within the rosters of potential network partners. Nontraced relationships were on average more recent relationships (40% of nontraced relations had started during the year prior to the survey vs. less than 30% for traced relations), and nontraced relationships were also more likely to have ended by the time of the survey than traced relationships. For example, among relationships having started more than a year ago, 64.2% of the traced relationships of women were still ongoing at the time of the survey but this was the case for only 28.1% of the nontraced relationships.

Table 3: Characteristics of nonmarital relationships between two residents of Likoma Island reported during the sexual network survey

	Relations reported by women		Relations reported by men	
	Traced in HH rosters	Not traced in HH rosters	Traced in HH rosters	Not traced in HH rosters
Context of initial meeting				
Place of first meeting				
In Likoma	87.0	80.2	76.6	79.3
Occasion of first meeting				
In school	40.8	40.7	33.1	32.4
Mganda dances	31.8	23.5	32.5	32.4
During business trip	5.9	16.0	7.5	3.8
On the steamer	6.9	6.2	11.1	16.2
At a religious meeting	11.8	11.1	10.8	13.3
Type of relation				
Did not know each other	20.0	29.1	21.2	26.6
Relatives	7.54	2.3	10.5	1.9
Friends	31.5	41.9	32.5	26.6
Acquaintances	39.0	23.3	34.0	34.9
Timing & duration of relationships				
Started w/in last month	5.9	7.1	4.9	6.3
Still ongoing	53.3	57.1	50.0	50.0
Started w/in last year	20.2	33.7	24.7	32.3
Still ongoing	52.5	39.4	53.9	39.0
Started more than a year ago	73.5	58.2	70.0	59.8
Still ongoing	64.2	28.1	49.4	34.2
Frequency of encounter				
Weekly or more frequent	56.5	56.5	62.8	62.9
Condom use				
Never	32.0	30.1	32.4	22.4
Sometimes	42.6	50.7	35.8	43.0
Always	24.4	18.1	29.7	30.8
HIV risk perception				
Worried a lot	12.7	19.0	14.6	12.1
Worried a little	26.5	32.1	24.1	32.7
Not worried at all	58.8	45.2	59.9	52.3
N	344	51	401	88

Notes: Reported numbers in the Table are percentages.

5.3.4 Indegree distributions

While we have focused so far on reports made by respondents during the sexual network survey, the inclusion of individuals within the sexual networks is further defined by the distribution of indegrees (= the number of times a respondent is nominated by someone else during the survey). The distributions of indegrees over three years and over one year prior to the survey are depicted in Figure 7. These distributions differ significantly from the outdegree distributions described in Section 5.3.1: over the full reporting period, the mode of the indegree distribution is one, and a large number of respondents have an indegree of zero. Only slightly less than 20% of all respondents were nominated by more than two other respondents during the survey. Among respondents who themselves nominated more than two partners, this proportion is only raised to 24%. There were no significant differences in indegrees between men and women. Outdegree and indegree distributions differ because *(i)* some network members have had only partners who lived outside of the sample (and thus are not interviewed), *(ii)* women reported many fewer partnerships than men (see Section 5.3.1) and *(iii)* the limit of at most five partnerships to be reported may have resulted in some respondents not being nominated by their partners during the survey.

Figure 8 displays the indegrees of contacts (= the number of times each network member *who was not a survey respondent* was nominated during the survey). The mode of this distribution is one, and only a handful of network members who were not interviewed were reported more than once. In this distribution, nobody has a degree of zero because being nominated by at least one respondent is the criteria for inclusion in the network.

5.3.5 Total degree distributions

The combination of outdegrees and indegrees leads to the definition of *total degree* distributions: these distributions combine the partnerships reported by a respondent with the partnerships others report about a respondent. Figure 9 thus ignores the difference between reporting and being reported, and considers that a *relationship exists between two individuals as long as it is reported by at least one of the two partners*. All sexual relationships that are reported by at least one partner are thus included. Whereas most studies of sexual behaviors in SSA are based on individual reports of partnerships (outdegrees) (Cleland et al. 2004), several analyses derived from the LNS (Helleringer and Kohler 2007; Jones, Helleringer, and Kohler 2007) build on *total degree distributions*. The average total degree of women over the three years prior to the survey was 2.2, vs. 2.6 for men ($p < 0.01$). This was the case even though a slightly higher proportion of males had no partnerships over this time span (Figure 9a). During the year prior to the survey, the average total degree of women was 1.55 vs. 1.81 for men ($p < 0.01$). 6.7%

of women and 12.6% of men had five or more partnerships. Only very few respondents ($N = 27$) were not sexually active over the entire recall period.

Figure 7: Indegree distributions among survey respondents, by gender

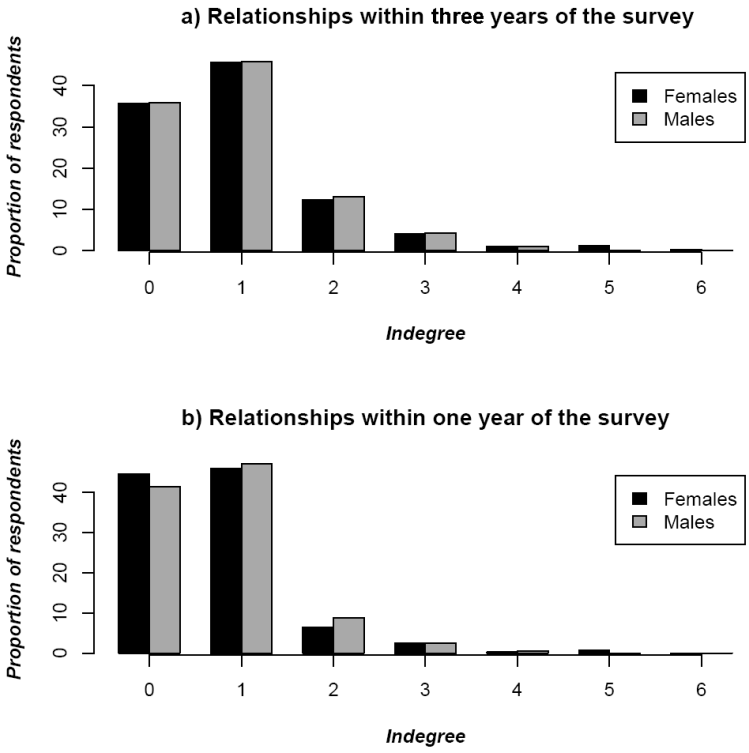


Figure 8: **Indegree distribution among nonsurveyed network members, by gender**

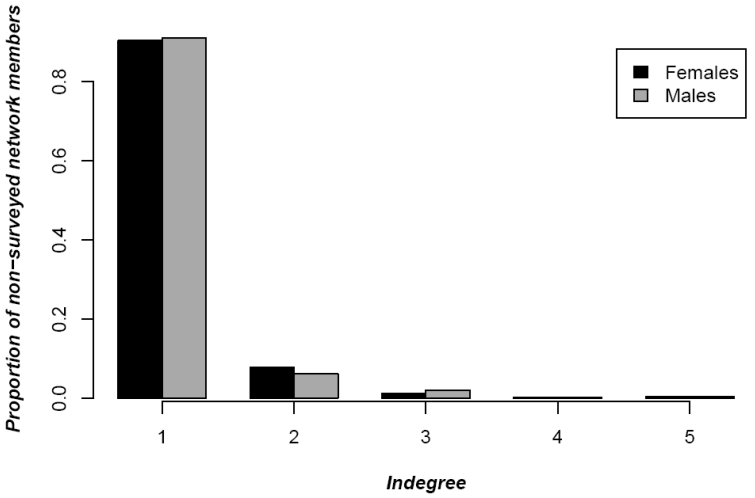


Figure 9: **Total degree distributions among survey respondents, by gender**

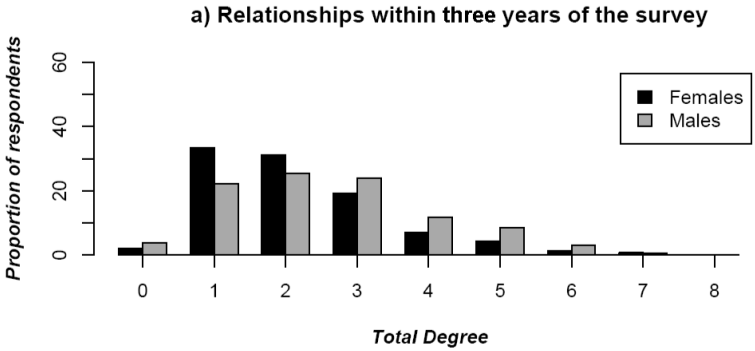
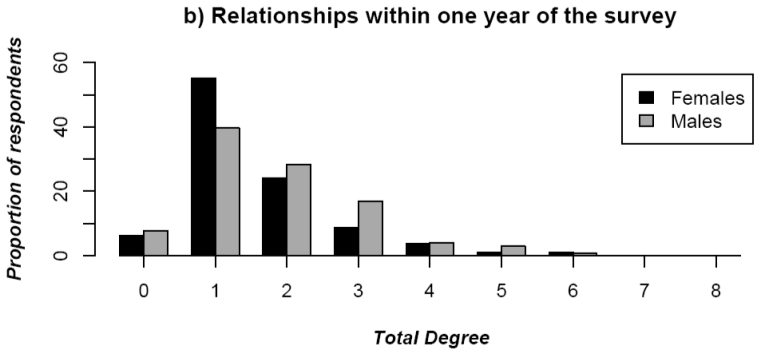


Figure 9: (Continued)



5.3.6 Comparison of total degree distributions and outdegree distributions:

In this section we compare systematically what respondents report from their own sexual networking, to measures of sexual risk-taking that also include reports made by partners (Tables 4 and 5). Graphically, it appears that the gender differences in total degree largely parallel differences in outdegree described above (Section 5.3.1). The correlation between total degree and outdegree is high as it reaches 0.85 among all respondents. There are significant differences between male and female respondents; however, the correlation coefficient for males is 0.92, whereas it is only 0.76 for females. This indicates that for this study, as has been noted elsewhere (Nnko et al. 2004), women tend to report fewer relationships than men do. And as a result, the total degree of women is often higher than their outdegree. This is the case for 30.3% of female respondents vs. only 20% of male respondents.

Furthermore, the patterns of differences between total degree and outdegree vary not only by gender, but also by age and marital status (Tables 4 and 5). In particular, the largest differences are observed among never-married women under age 25 who self-report only 70% of the total number of relationships according to their total degree. This gap between total and outdegree is much narrower for males and ever-married female respondents, who generally report between 85–90% of the relations they are reported to have engaged in.

Table 4: Average total degree and outdegree by gender and age among never-married respondents

	Female respondents			Male respondents		
	Total degree	Outdegree	n	Total degree	Outdegree	n
Age groups						
Less than 20	2.59(1.61)	1.62(1.08)	93	2.21(1.44)	1.92(1.32)	75
20–24	2.38(1.53)	1.89(1.16)	66	2.69(1.49)	2.35(1.41)	109
25–29	2.44(1.20)	2.27(1.22)	18	3.91(1.93)	3.29(1.62)	24
30–34	1.80 (1.30)	1.40 (1.67)	5	1.12 (0.99)	1.00(1.06)	8
35 and older	1.50 (0.57)	1.25 (0.50)	4	3.25 (1.70)[a]	3.00(1.63)[a]	4

Notes: A test of a linear trend in degree across age groups was significant at the .1 level.
Standard deviations are in parentheses.

There are several trends in the reporting of sexual partnerships by age that emerge within this study. On the one hand, we were not able to detect any significant differences in the reporting of partnerships among never-married women over age 30. This might be due to the fact that there are few women in their 30's who have never married, and the statistical test of trends might lack power. Among never-married males, on the other hand, both outdegree and total degree appear to increase significantly with age. Among ever-married women, total degree and outdegree appear to decline with age, and this pattern occurs across all types of relationships identified in the LNS. For men, only the total number of nonmarital relationships (total degree) appears to decline with age. In contrast, this is not the case for nonmarital relationships reported by men (outdegree). This finding possibly indicates that women are reluctant to report partnerships with older men, or alternatively, that older men may be more likely to exaggerate the extent of their sexual networking, especially with younger women.

5.4 Analysis of network data quality

Finally, we analyze issues related to the representativeness and validity of the sexual network data we collected on Likoma.

Table 5: Average total degree and outdegree by gender and age among ever-married respondents

	Female respondents			Male respondents		
	Total degree	Outdegree	n	Total degree	Outdegree	n
All relations						
Less than 20	2.20(1.05)	2.05(0.94)	20	–	–	0
20–24	2.57(1.35)	2.00(0.95)	93	2.58(1.43)	2.25(1.26)	31
25–29	1.96(1.08)	1.64(0.81)	109	2.86(1.46)	2.57(1.38)	65
30–34	1.53 (0.81)	1.48(0.72)	60	2.55(1.31)	2.28(1.27)	49
35 and older	1.62 (0.79)[a]	1.50(0.75)[a]	32	2.34(1.25)	2.12(1.22)	56
Nonmarital relations						
Less than 20	1.65(1.22)	1.35(0.98)	20	–	–	0
20–24	1.79(1.47)	1.19(1.06)	93	2.00(1.63)	1.42(1.26)	31
25–29	1.12(1.13)	0.78(0.84)	109	2.00(1.57)	1.61(1.38)	65
30–34	0.66(0.81)	0.56(0.72)	60	1.51(1.17)	1.26(0.99)	49
35 and older	0.87(0.94)[a]	0.78(0.83)[a]	32	1.37(1.28)[a]	1.19(1.28)	56

Notes: [a] A test of a linear trend in degree across age groups was significant at the .01 level.
Standard deviations are in parentheses.

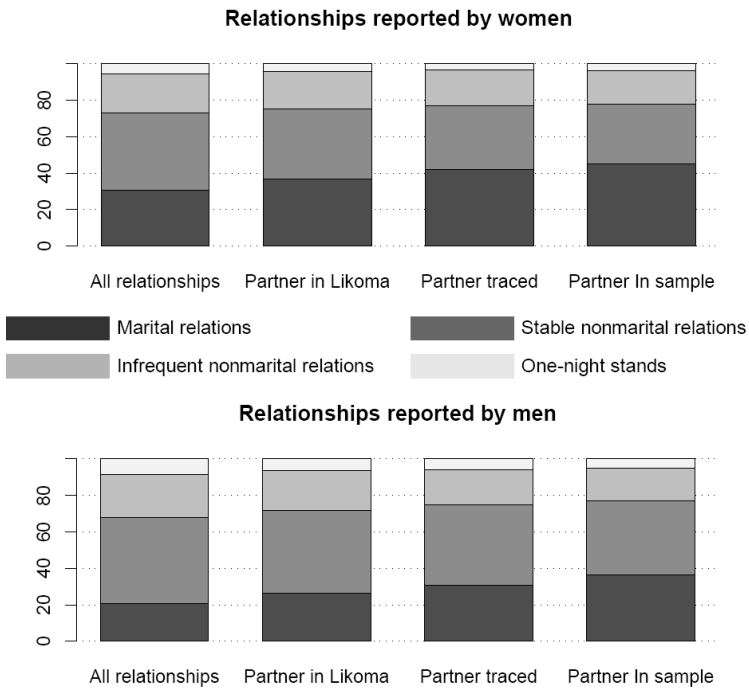
5.4.1 Selectivity of the tracing process

Our previous analyses have documented that the sexual relationships captured in the LNS sexual network survey neither represent the complete set of the sexual relationships in which respondents were engaged in, nor a random sample of this set. The relationships that are captured in the LNS –as in any other survey of sexual behaviors– are a selected subset of respondents' sexual relations (see also Section 3). For example, as shown above, marriages and more stable sexual relationships were systematically more likely to connect two partners residing on Likoma, and they were also more likely to be traced during the sexual network survey.

In Figure 10 we illustrate some of the implications of this selectivity on the composition of the sexual networks that can be constructed using the LNS data. For example, while marriages represent only 20% of all relationships of men and 30% of relationships of men, marital relations become gradually more prevalent at each stage of the tracing process in Figure 10. This is the case because marriages are on average 17% more likely to be traced than nonmarital relationships, even when both partners reside on the island.

As a result, roughly 40% of the relationships between two LNS survey respondents were marriages, and due to the selectivity of the data collection and linkage process, the LNS potentially overestimates the role of relatively stable sexual relationships in the sexual networks of young adults on Likoma Island.

Figure 10: Characteristics of relationships reported during the sexual network survey at consecutive stages of the tracing and linking processes



5.4.2 Jointly reported relationships

While other studies of sexual behaviors rely solely on self-reports of sexual partnerships, we are able to assess the level of inter-partner agreement on a series of behaviors in our data. We focus here on descriptive results about whether two partners agree that they have been in a sexual relationship. Accurate reporting of sexual behaviors would imply

that each relationship is reported by both partners in the relationship. In reality, however, reports of sexual relationships are often discordant: they are reported by one, but not the other partner. In our study, the 845 "in-sample" relationships (Figure 6) are potentially reported by both partners. This was the case for 57.7% of all partnership reports (Table 1). That is, close to 95% of marriages were jointly reported by both spouses, and 36% of reports of extramarital relations were concordantly reported by both partners. Table 1 shows that the proportion of reciprocated reports generally increases with the strength of a relationship: reports of stable nonmarital partnerships are generally more reliable than reports of one-night stands. The concordance of reporting also increases for ongoing relationships. For example, 54.2% of ongoing nonmarital relationships are jointly reported by both partners, as compared to only 25% of nonmarital partnerships that have ended more than a year prior to the survey.

The proportion of concordantly reported nonmarital relationships appears lower than proportions of concordant reports observed in other studies of sexual networks (Bell, Montoya, and Atkinson 2000). However, this lower concordance rate is likely to be due to *(a)* the longer recall period for sexual relationships in the LNS (up to three years prior to the survey as compared to 30 days in Bell, Montoya, and Atkinson 2000), *(b)* the limit of at most five network partners may have resulted in truncation of some reports. In addition, virtually all studies of inter-partner agreement in reporting of sexual relationships have been conducted among members of high-risk groups (Bell, Montoya, and Atkinson 2000; Adams and Moody 2007). It is possible that the social desirability biases generating lower inter-partner agreement in sexual network surveys may be stronger among the general population investigated here than they are among high-risk groups. Indeed among high-risk groups, stigmatized behaviors such as nonmarital or casual sexual relations are the norm rather than exception, whereas this is not the case among the general population.

5.5 HIV prevalence

Overall response rate for the biomarker data collection was 74% for women and 65% for men (among individuals who previously agreed to participate in the sexual network survey). 21.7% of men refused to be either counseled or tested vs. only 15.4% of women. 13.5% of men and 11% of women could not be found at home at the time of the biomarker team's visit. Overall participation rates varied widely between villages, ranging from 54% to 82% (see Figure 2). In total, 597 respondents were tested for HIV, and among those tested, the data show an overall HIV prevalence rate of 10.6% (95% CI 7.2%-13.9%) for females and 4.7% (95% CI 2.1%-7.3%) for males. Four study participants presented discordant test results (0.6%) and were referred to the local hospital for further testing. They are considered as HIV-negative in the analyzes we conducted using the HIV biomarker data (Helleringer and Kohler 2007).

6. Conclusion

The ***Likoma Network Study*** (LNS) constitutes—to our best knowledge—the first sociocentric study of sexual networks among a general population of SSA. Using these data, Helleringer and Kohler (2007) for instance, document the existence of a large and robust sexual network connecting young adults residing on the island. Similar sexual networks have been associated with epidemic spread of STIs in high-risk groups in developed countries (Moody et al. 2003; Newman 2002; Rothenberg et al. 1998; Potterat et al. 2002), but prior to this study it has never been documented among the general population of a sub-Saharan setting where an HIV epidemic had become generalized (see also Helleringer and Kohler 2007, 2008; Helleringer et al. 2007, 2009a, 2009b).

In the present paper, we describe and evaluate the data collection procedures implemented during the LNS. We provide initial results relating to the socioeconomic context of the island, the prevalence of HIV in the study population, the quality of the sexual network data and the size, and composition of the observed sexual networks. Our analyses indicate that the LNS was able to trace the large majority of sexual relationships reported by survey respondents: for example, when a survey respondent reported that his/her partner resided on the island at the time of the survey, we were able to identify the nominated partner in preestablished rosters of potential network members more than 8 times out of 10.

In summary, our analyses thus provide clear evidence that the collection of relatively accurate sociocentric sexual network data for the general population is feasible in a sub-Saharan context. In analyzing the LNS data; however, it is also important to recognize several limitations. *First*, the LNS did not cover all villages of the island: only seven villages representing a little over 50% of the total population were included in our initial sampling frame. In addition, it did not include all sexually active age groups (e.g., 12–17 and 35+ years old persons) and thus may have left out members of sexual networks that potentially play an important role in the diffusion of pathogens within the general population (e.g., older males, younger adolescents). *Second*, a large proportion of all relationships could not be traced during the study, either because nominated partners were outside of the study population (e.g., mainland partners) or because the information provided by respondents was not sufficient to allow accurate tracing. Similar to other sociocentric network studies (Bearman, Moody, and Stovel 2004), our data is thus affected by "incomplete network bias" (Doherty et al. 2005). *Third*, our analyzes further highlighted the selectivity of this partner tracing process. On the one hand, we showed that more stable relationships were much more likely to be traced. On the other hand, we also showed that the probability of tracing a partner nominated during the sexual network survey may be related to the timing and duration of a relationship. As a result, patterns of connectivity and overlap between relationships—which contribute significantly to the spread of HIV in

sub-Saharan populations (Morris and Kretzschmar 1997))—may be misrepresented. The networks represented in the LNS data therefore potentially overestimate the contribution of relatively stable sexual relationships to the diffusion of HIV through sexual contacts. *Fourth*, we showed that, due to recall/reporting problems, the reliability of the network data is potentially limited in the case of relationships that were not ongoing at the time of the survey.

Some of these limitations (e.g., selectivity of the tracing process) are inherent to sociocentric studies, but others are due to limited resources available during the LNS and were remedied during a follow-up study conducted between October 2007 and April 2008. During this later study, we interviewed close to 2,200 respondents aged 18-50 residing in all villages of the island. The coverage of the study described here has thus become more complete and the biases just enumerated may have been substantially reduced during the follow-up. Despite the limitations described above, therefore, the LNS is likely to substantially improve in several important dimensions the available data on sexual networks in sub-Saharan Africa as compared to other data sources that are primarily based on ego-centric surveys of sexual networks. In particular, egocentric surveys such as the DHS have no choice but to take self-reports made by respondents at face value, and such self-reports great underestimate the extent of sexual relationships—and specifically, of nonmarital relationships—in sub-Saharan populations. In contrast to egocentric data, the sociocentric design of the LNS provides possibilities to evaluate the data quality by determining rates of inter-partner agreement about sexual relationships (see Section 5.4.2). In addition, due to its sociocentric design, the LNS provides more detailed data on the extent and structure of sexual networks than is available from egocentric surveys. Such detailed information about sexual network patterns are likely to improve our ability to accurately model and analyze how HIV and other sexually transmitted infections are spread through sexual contacts.

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