Estimating the size of key populations: current status and future possibilities

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Abstract

Purpose of review—Estimation of key population sizes is essential for advocacy, program planning, and monitoring of HIV epidemics in these populations. A review of recent publications on population size estimation among key populations including MSM, people who inject drugs, and male and female sex workers was conducted to identify and assess current practices at the global level.

Recent findings—Studies have used multiple methods including capture–recapture, service multiplier, and unique object multiplier. Other studies apply census and enumeration, often before implementation of a behavioral survey. Network scale-up is used infrequently. Newer methods or variations of existing size estimation methods have emerged that are applied solely within surveys.

Summary—A range of size estimation methods is available. All methods rely on theoretical assumptions that are difficult to meet in practice, are logistically difficult to conduct, or have yet to be fully validated. Accurate and valid key population size estimates remain as necessary as they are challenging to undertake; the concurrent use of multiple methods may be justified to facilitate the triangulation and interpretation of the resulting estimates. Formative assessment can help inform the appropriateness and feasibility of different size estimation methods.

Keywords

INTRODUCTION

The HIV/AIDS epidemic in many parts of the world has been driven by key populations at increased risk of HIV infection. The epidemic in South and South-East Asia, Central Asia, Central America, and Central and Eastern Europe has been concentrated among the key populations including men who have sex with men (MSM), people who inject drugs (PWID), and male and female sex workers [1]. Lack of reliable and valid population size data, along with stigma and discrimination against these populations, continue to challenge

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design, development, and implementation of appropriate prevention, care, and treatment interventions targeting key populations [1]. In response, UNAIDS/WHO revised the 2003 guidelines on population size estimation in 2010 [2■], and subsequently, in collaboration with PEPFAR, implemented regional population size estimation capacity building workshops. Since then, several countries have conducted size estimation studies among key populations including MSM, sex workers, and PWID. In addition, funding organizations such as the Global Fund to Fight AIDS, Tuberculosis and Malaria and the President's Emergency Plan For AIDS Relief (PEPFAR) have begun to require and encourage countries to conduct population size estimates to monitor intervention coverage and reach, and to monitor the epidemic among key populations.

Reliable size estimates are important for several reasons. Size estimation data are needed to inform the design of HIV prevention, care and treatment programs; assist with the monitoring and evaluation of these programs; and advocate for implementation of new services. UNAIDS's global, regional, and national HIV estimates for all but generalized HIV epidemic settings use key population size estimates to estimate the number of new and prevalent infections, the number of people in need of care and treatment, and the number of AIDS deaths. In this review, we focus on the current state of the size estimation activities among key populations. We briefly describe the methods that have been used, highlight some of the successes and challenges to these methods, and the options that these methods provide in informing the programs. We also describe newer methods that are being proposed and/or used, and future directions of population size estimation activities.

SUMMARY OF SIZE ESTIMATION METHODS

There are two broad categories of methods used to estimate the size of key populations. Methods under category one (census and enumeration, multiplier, and capture–recapture) are used to collect data directly from the key population at risk, including existing data from related institutions. Methods under category two (population survey, network scale-up) are used to collect data from the general population.

Using census and enumeration can be a straight-forward way to produce credible lower-limit estimates of population size. These activities are costly and may miss hidden or hard to reach populations. Capture– recapture (CRC) [2■] has a long history but can be complex to implement. The addition of a third capture source may yield more stable and reliable estimates but requires more complex data analysis. The theoretical assumptions underlying CRC are difficult to meet or to assess (closed population, unique matching, independence of sources, and equal likelihood of capture).

The multiplier method compares two independent sources of data for populations to estimate the total number in the population. The first source is a count or listing from program data including only the population whose size is being estimated, and the second source is a representative survey of the populations whose size is being estimated. Another version of multiplier method involves the distribution of a unique object to members of the population. It relies on access to members of the key populations in which a particular unique object is distributed randomly. The multiplier method is widely used and relatively cost efficient.

Multipliers based on different data sources can yield vastly different results because of the variations in the operational definitions of key populations. It requires accurate and timely demographic and geographic information to allow for linking with additional data sources, and is dependent on the quality of data sources. The multiplier method is often used as part of surveys in high-risk populations, and a lack of representativeness of the resulting survey samples can be an additional source of bias [2▪].

Another size estimation method includes the addition of direct questions about high-risk behaviors (that define key populations) in general population-based surveys. Because only a minority of the general population practices such high-risk behaviors, large sample sizes are required to generate acceptably precise estimates. Further, participants may deny engaging in stigmatized or illegal behaviors, and adding such direct behavioral questions may risk exposure and breaches of confidentiality. Household-based sampling does not reach people in institutions, homeless persons, or mobile populations.

An alternative to direct survey questions is the network scale-up method (NSUM) [2▪,3], a relatively new method in HIV surveillance. NSUM allows for the concurrent estimation of sizes of key populations within the same study without requiring access to a key population. The survey respondents are not asked direct questions about their own behaviors; instead, NSUM probes respondents' personal network sizes and the number of high-risk individuals within them. Some inherent biases of NSUM include the respondents' social isolation or their ignorance of high-risk behaviors (transmission error) among their acquaintances. Also, estimating their personal network size can be complex or cognitively demanding for some respondents. Table 1 provides a brief summary of strengths and limitations of each of these methods.

METHODS

For this review, we have included articles published during 2011– 2013, that is, after the 2010 publication of the UNAIDS/WHO population size estimation guidelines [2▪] and subsequent regional capacity building workshops conducted by PEPFAR and UNAIDS. During this period, a significant number of population size estimation studies have been implemented, and some have been published.

We conducted a systematic search of publications using EMBASE and PUBMED that either reported findings from population size estimation activities among key populations, or included discussions of any of the population size estimation methods, or proposed a new or modified size estimation method. Only publications related to key populations (MSM, sex workers, and PWID) were considered. Studies selected for this review include those that report findings from size estimation studies among the key populations.

FINDINGS

Table 2 is a summary of selected studies that highlight the study design (method used), population, and major findings. The multiplier method was the most commonly used and was often applied as part of a survey activity. Multipliers included both unique object multipliers and service multipliers [2▪]. Mapping and limited field ethnography

accompanied some of these surveys. Three studies reported using CRC, three studies reported using NSUM, one study reported using USA State-specific data, and one study reported conducting meta-analysis with behavioral data from population-based surveys.

In most cases, the size estimation studies were conducted as part of key population surveys and surveillance activities. In Pakistan [4], size estimation among FSW was conducted, along with a mapping exercise, before a behavioral survey. In El Salvador [7], size estimation was conducted among MSM and FSW in conjunction with behavioral survey using respondent-driven sampling (RDS). In Mauritius [8] both unique object and service multipliers were used with RDS to estimate the size of PWID population, including HIV-positive PWIDs.

Paz-Bailey *et al.* [7] distributed unique objects prior to the implementation of the survey, and arrived at estimates using the multiplier formula. Lieb *et al.* [24] calculated averages using findings from two statistical models developed to estimate the total State-specific percentage and number of MSM in the USA. The two models rely on previously estimated proportions of MSM residing in rural, suburban, and urban areas (model A), and on State-level data on number of same-sex male unmarried partners and number of households (model B) [24]. Purcell *et al.* [10] conversely, conducted meta-analysis of behavioral data from United States population-based surveys to estimate national MSM population size. As the estimates by Purcell *et al.* [10] are linked with United States census data, there is the possibility of updating the number of MSM (as well as rates and ratios) annually based on updated United States census population figures. The estimates calculated by Lieb *et al.* [24], and Purcell *et al.* [10], can help understand the HIV epidemic in the USA and also facilitate resource allocation, program design, and evaluation of policies and programs.

NSUM is a relatively new method that has not yet been widely used to estimate the size of key population. The study in Japan [11■] estimated the size of MSM and when adjusted for transmission error [3], the estimated MSM size increased by 50 times. Similarly, the estimates of the number of heavy drug users in a Brazil study (defined as people who had used illegal drugs other than marijuana more than 25 times in the past 6 months) [12] were 5–10 times higher than previous estimates obtained using other methods.

Dombrowski *et al.* [17■] innovatively used the CRC entirely within a behavioral survey. RDS was used to recruit the first capture using the Internet (Craiglist), and the second capture was based on respondents' friends in their personal networks. Recapture sampling was based on links to other respondents derived from demographic and 'tele-funken' matching procedures —the latter being an anonymized version of telephone numbers. This technique made it possible to estimate the population size without physically recruiting a second sample.

DISCUSSION

The most common method applied in the past few years has been the multiplier method, suggesting that researchers should explore extensions to this method and hybrid approaches utilizing several methods simultaneously. Estimating population sizes using the service multiplier method requires programs that serve the key population and produce reliable

service data. Programs implemented in some countries often lack good-quality data by which to derive acceptably accurate multiplier-based estimates. Estimating population size using unique object multipliers relies on access to and reach of the members of the key population through outreach or health workers to distribute the unique object. At the second stage, surveys are then used to estimate the proportion, which had received the unique object. The surveys are expected to recruit a representative sample, and the two samples (those who received the unique object in the first stage and those who are enrolled in the survey and probed for receipts of the unique object in the second stage) must be independent of each other.

In the multiplier method, the population size estimate is derived within the statistical framework of the capture– recapture method. Adding an additional stage of recapture could provide more robust three-source estimates that could also adjust for dependence between sources via log-linear modeling. Further use of service or benchmark data will depend on information to uniquely identify individuals for linking the different sources of data, a key condition of the CRC method. Another key condition of CRC is equal likelihood of capture, but RDS sampling in the recapture stage is assumed to be proportional to personal network size. Thus, Paz-Bailey *et al.* [7] adjusted the CRC estimate by weighting the RDS recapture by the respondent's personal network size. Berchenko and Frost [27] suggested an additional improvement to this approach by gathering information on network size during the capture stage (e.g., unique object distribution) for similar adjustment.

NSUM produces a population size estimate at the national level. Challenges to NSUM include the need for a population-based survey as well as adjustments to address transmission error (low social visibility of key populations).

A promising direction of research is the use of a single data source to derive at a population size estimate. The Laska–Meisner– Siegel (LMS) method, introduced in 1988 [14], enables estimation of a population size on the basis of a single survey. The LMS method requires asking survey participants about the last time they engaged in a well defined activity such as attending a venue or using some service in the previous K time units; based on this information, an estimate of the size of the target population during the K weeks is calculated [15]. Tate and Hudgens [16] generalized the LMS method for two-stage and three-stage sampling designs for size estimation across multiple venues (e.g., stage 1 – sample of venues within a city, stage 2 – sample of individuals attending these venues).

Behavioral surveys among key populations are being conducted around the world, and many of these surveys use RDS. The recent methods to estimate population sizes using a single RDS or other survey require more sophisticated statistical programming and analysis, which may restrict their wider use. Handcock, Gile, and Mar [18■] recently proposed a Bayesian approach to estimate population size of key populations using a single RDS survey. Their approach uses an approximation of RDS by successive sampling (probability proportional to size without replacement sampling), in which successive sampling samples are simulated and the population size and the distribution of personal network size are assumed to be known, though sensitivity analyses for unknown population sizes can be performed through use of different prior distributions that may incorporate previous or concomitant information

about the population size. Dombrowski's [17■] technique derives population size estimate without recruiting a second sample, minimizing the risk of breach of confidentiality and anonymity. In the absence of good quality service data or sufficient resources for population size estimation using multiple sources, a single-source method may be a feasible and costeffective approach, with collaboration of quantitative scientists and technical assistance providers. Providing public access to individual size estimation data sets may accelerate development of single-source methods or other novel approaches.

CONCLUSION

Key population size estimates continue to have limitations; estimates are uncertain and different methods are likely to give very different results. Variability in quality of service data (multiplier method), assumptions that are hard to meet (CRC), and transmission error (NSUM) can make population size estimates substantially uncertain. Use of more than one method to derive estimates may help to interpret the range of estimates and determine the best one based on the most acceptable method. Solutions have included best guesses based on evidence from multiple sources and Delphi panels (the Delphi method is a structured communication technique, developed as a systematic, interactive forecasting method which relies on a panel of experts) [28], resulting in some midpoint or median among the available estimates. These approaches depend on subjective judgments of subject matter experts or key population members themselves. When feasible, multiple estimates may be bracketed by a minimum estimate derived from good quality service data and a maximum estimate derived from census data.

In the USA or where multiple studies have been conducted, more statistically rigorous methods can be used to combine information and derive best estimates. To estimate the number of MSM in the USA, Purcell *et al.* [10] performed a meta-analysis of seven national, population-based surveys in which the survey was treated as a random effect to account for between-survey variability [29]. This approach could be applied where several studies have been performed on the same population.

Looking forward, thorough planning and preparation will improve the validity of key population size estimation. It is important to inventory your capacities to conduct size estimation such as experience with key population programs and experience with sampling methods to implement population surveys such as IBBS. Also important is inventories of your existing data – sources of data in which the at-risk members of a population are identified, including the quality of the data, ease of access and sharing the data, and legal or other constraints to using the data. A formative assessment that includes members of the key population conducted before designing the study clarifies the social and geographical distribution of the key population and the likelihood that the study staff can reach them. Working with key population members in the community informs the selection of the most appropriate methods. Piloting the method(s) in a subset of the population and validating the method(s) in a known setting (e.g., a university), where possible, are important. Estimating population size is essential; however, the calculated estimates should be accompanied by the corresponding degrees of uncertainty.

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Papers of particular interest, published within the annual period of review, have been highlighted as:

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11■. Ezoe S, Morooka T, Tatsuya Noda T, et al. Population size estimation of men who have sex with men through the network scale-up method in Japan. PLoS One 2012; 7:2e31184.Combined an Internet survey with the network scale-up method. Using the survey results with the network scale-up method, the personal network size and MSM population size were estimated. Adjustment for transmission error was performed through use of 'the coming-out rate' for MSM among people they know.

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KEY POINTS

- Conduct a formative assessment to understand the availability of data sources and determine the feasibility of any method of population size estimation.

- Use multiple methods of size estimation.

- Optimize the use of population-based surveys by incorporating questions about key populations. The network scale-up method could be exploited in surveys like the Demographic and the Health Survey and AIDS Indicator Survey

- If using the multiplier method, use more than one data source to allow for multiple estimates and account for dependency of sources in the capture–recapture method.

- Include key population members in planning studies, and where feasible, pilot study methods in a subset of the population, and validate the methods in a setting of known population size.

Table 1.

Summary of methods for estimating the size of key populations [2[■]][a]

Methods	Strengths	Limitations	Recommendations	Author (reference)
Census: Count all members of the population; Enumeration: Develop a sampling frame and count all members of the population at the selected locations	Real count, not an estimate or sample; Can produce credible lower limit; Can be used to inform other methods	At-risk populations are often hidden, will miss some or many members of the population; Stigma may cause members to not identify themselves; Time-consuming and expensive	Prior to implementation conduct detailed mapping	Altaf et al. [4]; Comiskey et al. [5]
Capture–recapture: Size estimate is based on two independent captures (samples): Capture 1: 'tag' and count number tagged; Capture 2: 'tag' and count who is 'retagged' and who is 'first time tagged'	Relatively easy to do with access to population; Does not require much data	Relies on 4 conditions that are hard to meet: The two captures must be independent and not correlated; Each population member should have equal chance of selection; Each member must be correctly identified as 'capture' or 'recapture'; No major in/out migration	Use this method when census/enumeration is not feasible, or no or poor quality service data	Kimani et al. [6]
Multiplier method: Apply a multiplier (e.g., number receiving particular service/ having membership or number receiving a unique object distributed prior to a survey) to survey estimate (proportion of survey sample sharing same characteristic)	Uses data sources already available; Flexible in terms of sampling methods; first source need not be random, but second source should be representative of population	The data sources must be independent; The data sources must define population in the same way; Time periods, age range, geographic areas must be aligned; Data collected from existing sources may be inaccurate	Use when you already do or plan for a behavioral survey; The multiplier can be based on either accurate service provider data or results of distributing unique objects by outreach workers before the survey	Paz-Bailey et al. [7]; Johnston et al. [8]; Khalid et al. [9]
General population-based survey: Ask respondents if they engage in the behavior of interest (e.g., male–male sex, money for sex, inject drugs)	Surveys are common and familiar; Easy to implement if a survey is underway; Straightforward to analyze; Sampling is easy to defend scientifically ('gold standard')	Low precision when the behaviors are rare; Respondents may be reluctant to admit to stigmatized behaviors; Only reaches people residing in households (mobility); Privacy, confidentiality, risk to patients	Consider using with already planned general populationbased surveys	Purcell et al. [10]
Network scale-up is based on the assumption that people's social networks reflect the general population sampled in a survey	Can generate estimates from general population rather than hard-to-reach populations; Doesn't require survey respondent to disclose stigmatizing behaviors about him/herself	Average personal network size is difficult to estimate; Some subgroups may not associate with members of the general population; transmission error: Respondent may be unaware someone in his/her network engages in the behaviour of interest; Reporting bias (i.e., social desirability) may arise	Consider adding to already planned general populationbased surveys	Ezoe et al. [11[■]]; Salganik et al. [12]
Single-survey methods based on a single general population-based survey or RDS survey	One well designed survey; Do not need to reach the population multiple times	Participants need to be randomly selected or representative of population; Requires collecting network information	When conducting behavioral survey using respondentdriven sampling or other random survey	Chen et al. [13[■]]; Laska et al. [14]; Laska et al. [15]; Tate et al. [16]; Dombrowski et al. [17[■]]; Handcock et al. [18[■]] and RDS Analyst software (http://www.hpmrg.org)

[a] Adapted from UNAIDS/WHO Working Group on Global HIV/AIDS and STI Surveillance Guidelines on Estimating the Size of Populations Most at Risk to HIV (2010).

Table 2.

Summary of selected studies on population size estimation

Author (reference)	Study population	Study design	Major findings/highlights
Altaf et al. [4]	FSW street-based, home-based, and brothel-based.	Geographic mapping, census, and IBBS among street, home, and kothi-khanabased FSW, and brothel-based FSW	Mapping was essential as brothels were banned and SW operated either from the street or private apartments. Data validated through interviews with key informants
Paz-Bailey et al. [7]	MSM and FSW	Unique object multiplier using key chain distribution followed by RDS survey	Estimation of MSM and FSW who live in El Salvador. Use of respondent-driven sampling and unique object multiplier
Kimani et al. [6]	SW	Mapping and two-sample capture–recapture	As the enumeration was limited to the central part of the city of Nairobi, the calculated estimates may be lower than that would be obtained if the entire metropolitan area was enumerated
Johnston et al. [8]	PWID	RDS survey with unique object multiplier and service multiplier	Estimation of HIV-positive PWID, which highlighted the undetected HIV cases amongst and a potentially large gap in access to ART among PWID
Medhi et al. [19]	PWID	Multiplier method: service multiplier and interviews of IDUs recruited at hotspots identified thru mapping. Interviews assessed exposure to interventions	Quality of program data not assessed; long time periods of services coverage records (12 months); duplicate data cannot be excluded; eligibility criteria for receiving services and enrolment in survey not identical. Survey not a random sample
Sawitri et al. [20]	PWID	Multipliers generated from a communityrecruited survey applied to several benchmarks	The three multipliers provided consistent estimates. Estimates were lower than those from multipliers
Khalid et al. [9]	PWID, FSW, MSM	Unique object multiplier along with RDS survey; Services multiplier; Recapture of 2007 respondent driven sampling (RDS) survey participants during the 2011/2012 RDS survey	Use of Delphi method to synthesize the results of the methods. Not one method is standard for all populations
Okal et al. [21]	MSM, FSW, PWID	Multiple methods: service multiplier, review of published literature, and 'wisdom of the crowds'	Data from three sources shared with community representatives and stakeholders to finalize 'best' point estimates and plausible bounds
Chen et al. [13▪]	MSM	Modified LMS method	LMS method is simple to use and requires no private information, only that MSM in venues be willing to answer questions about the last time they visited
Raymond et al. [22]	MSM	Multiplier	Used service multiplier method and HIV prevalence-based estimation method. Derived multiple estimates for MSM and produced plausibility bounds based on point estimates derived from empirical data and corroborated by other data
Zhao [23]	PWID	Service multiplier	Estimate size of IDU population that uses needle exchange programs (NEPs). Then used RDS to obtain a sample of IDUs and find out which of them had used NEPs at least once in the period of the three months or never used NEPs. From this information, find the proportion of IDUs who have ever used NEPs in the period of the three months (a). The estimate of the size of IDU population is N/a
Lieb et al. [24]	MSM	Averages were calculated using the findings from two statistical models previously developed to estimate the total State-specific percentage and number of MSM	State-specific estimates, race-specific estimates. Major limitation: applying national data to State-level estimates
Purcell et al. [10]	MSM	Meta-analysis with behavioral data from population-based surveys was used to calculate population size estimates	Estimated the population size of MSM in the USA to obtain HIV and syphilis rates

Author (reference)	Study population	Study design	Major findings/highlights
Ezoe et al. [11•]	MSM	Network scale-up method with known population size estimation. Internet survey conducted among 1500 Internet users who registered with a nationwide Internetresearch agency	Calculated the 'coming out rate' for MSM. Prevalence of MSM among the total male population in Japan was estimated by dividing the rate of MSM in the average personal male network by this MSM 'coming out rate'. Large change in estimated MSM prevalence after adjustment for transmission error (~50×). Extremely short sampling period. The estimated 'known' populations corresponded well with the corresponding known sizes
Salganik et al. [12]	Heavy drug users	Network scale-up method. Used 4 different data sources to produce 5 estimates of heavy drug users	Generalized NSUM estimate is 5–10 times higher than previous estimate. Further comparative studies are necessary to get clarity if NSUM or more conventional estimates are producing more valid results
Guo et al. [25]	FSW, clients of FSW, DU, PWID, MSM	Network scale-up method	Produced estimates for FSW, clients of FSW, DU, and IDU consistent with national guidance; however, yielded a low MSM population size estimate. Obtaining a representative sample was challenging in a location which has over 28 million residents. Poststratification measures were done to adjust for the distribution of key demographic characteristics. Survey participants may have had different interpretations of the definitions of key populations and acquaintances, which may have affected the accuracy of the reported information. The study suffered from the inherent biases of NSUM due to transmission effect, barrier effect, and estimation effect
Dombrowski et al. [17•]	Metham phetamine Users	Capture–recapture method. Recapture sampling was based on links to other respondents derived from demographic and 'telefunken' matching procedures	Takes steps in alleviating the need for two distinct sampling of the population, and the need for subject anonymity throughout the matching process when dealing with illegal or stigmatized behavior
Bollaerts et al. [26]	Ever injecting drug user	Benchmark multiplier	Used data from national HIV/AIDS register and a sero-behavioral study of drug users. Statistical methods were used to impute missing information on probably mode of HIV transmission (e.g., IDU) and to account for lack of follow-up on non-AIDS cases (i.e., no information on vital status of HIV+/AIDS-cases). Monte Carlo simulation was used to obtain confidence intervals
Comiskey et al. [5]	PWID, SW and MSM	Enumeration, multiplier and benchmark along with IBBS, and capture–recapture	Development of a framework for national prevalence estimates and program planning

DU, drug users; LMS, Laska–Meisner–Siegel; PWID, people who inject drugs; RDS, respondent-driven sampling; SW, sex workers.