



## Sampling hard-to-reach populations with respondent driven sampling

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### Abstract

Cost effective and targeted prevention, intervention and treatment programs for hard-to-reach populations at risk for HIV and other infections rely on the collection of quality data through biological and behavioral surveillance surveys (BBSS). Over the past decade, there has been a global expansion of BBSS to measure the prevalence of HIV and other infections, and related risk behaviors among injecting drug users, males who have sex with males, and female sex workers. However, a major challenge to sampling these hard-to-reach populations is that they are usually stigmatised and/or practice illegal behaviors which, in turn, make them difficult to access and unwilling to participate in research efforts. Over the past decade, respondent driven sampling (RDS) has become recognised as a viable option for rigorous sampling of hard-to-reach populations. This paper introduces RDS methods and describes some of the advantages and challenges to implementing and analysing surveys that use RDS.

**Keywords:** Respondent driven sampling, most-at-risk populations, HIV, behavioral surveillance

### Introduction

Cost effective and targeted prevention, intervention and treatment programs for hard-to-reach populations at risk for HIV and other infections rely on the collection of quality data through biological and behavioral surveillance surveys (BBSS) (Zaba et al. 2006; Mills et al, 2004; Pisani et al, 2003). Over the past decade, there has been a global expansion of BBSS to measure the prevalence of HIV and other infections, and related risk behaviors among injecting drug users (IDUs), males who have sex with males (MSM), and female sex workers (FSWs) (WHO and UNAIDS, 2002; Magnani et al, 2005; UNAIDS, 2007). However, a major challenge to sampling hidden populations is that they are usually stigmatised and/or practice illegal behaviors which, in turn, make them difficult to access and unwilling to participate in research efforts.

Many studies of hard-to-reach populations have relied on a fairly simple and inexpensive convenience sampling method known as 'snowball sampling'. Snowball sampling is a chain referral sampling method that relies on referrals from initial subjects to generate additional subjects. This sampling method produces biased samples because respondents who have a large number of social connections are able to provide researchers with a higher proportion of other respondents who most likely have characteristics similar to that initial respondent (Erickson, 1979). The result is a final sample that is over-represented by the characteristics of

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those respondents with more social connections and underrepresented by the characteristics of those respondents with fewer social connections, usually the more hidden group members. This limitation produces a sample whereby no statistical inference from the sample to the larger target population (all group members in the study area) can be made with accuracy (Van Meter, 1990).

**Table 1: Snowball Sampling Biases and Respondent Driven Sampling ‘Solutions’**

<b>Snowball Sampling</b>	<b>Bias Issue</b>	<b>Respondent Driven Sampling ‘Solution’</b>
Respondents may refer to an unlimited number of peers	<ol style="list-style-type: none"> <li>1. Differential recruitment: Those with larger network sizes can recruit more peers, who are likely to have similar traits</li> <li>2. Clustering: leads to lower effective sample size</li> </ol>	Limiting recruitment coupons to individuals limits clusters, thereby reducing recruitment bias and high homophily
Social network properties are ignored	<ol style="list-style-type: none"> <li>1. Clustering by network traits cannot be measured</li> <li>2. Size of social networks affect probability of selection</li> </ol>	<ol style="list-style-type: none"> <li>1. Coded coupons permit linking respondent with recruiter and recruits</li> <li>2. Analysis weighted to account for measurable network properties</li> </ol>
Respondents refer, surveyors must find referred	Only members accessible to ‘outsiders’ participate	Peers recruit peers, which includes ability to exert social influence where surveyors likely have none; surveyors remain in office
Convenience sample – analysis limited to proportions of sample, not generalisable	Probability of selection is unknown	Collect size of peer network to calculate probability of selection within network, i.e., sampling weight; use known network properties to account for clustering effects

Since its introduction in a seminal article published in 1997 by Dr. Douglas Heckathorn, Respondent Driven Sampling (RDS) has grown in popularity as an efficient and robust means to sample hard-to-reach populations at risk for HIV (Heckathorn, 1997). RDS is similar to snowball sampling in that it requires that target population members are socially networked so that participants can invite their peers to participate in a study. However, RDS incorporates numerous theoretical assumptions borrowed from several disciplines, including network theory, physics, statistics and mathematics, to reduce the numerous biases found in standard snowball sampling methods. Basically, RDS, like snowball sampling, begins with an initial set of participants who begin the recruitment process. These initial participants are known as seeds and they are often found through existing peer outreach groups or organisations who work with the target populations. A major difference between snowball sampling and RDS is that seeds recruit their peers (rather than identifying them to an investigator) using a set number of uniquely coded coupons which are redeemed at a fixed interview location within a set period of time (e.g., 10 days). RDS peer-to-peer recruitment removes selection bias of the survey staff and the coupon quota minimises biases associated with the over-representation of those participants with large networks (Heckathorn, 1997; 2002). In addition, RDS requires that recruitment continue far beyond the seed and his or her recruits. The recruits of seeds (wave 1) are also expected to recruit their peers (wave 2), who in turn enroll in the survey and receive their own set of recruitment coupons to use in recruiting their peers (wave 3). This process is encouraged until the final sample comprises long recruitment chains made up of several waves of participants (sometimes as long as 20 waves). Long recruitment chains allow for deeper penetration into the target population networks and help to ensure that the sample meets several theoretical assumptions indicating representativeness (Heckathorn, 1997; 2002; Salganik & Heckathorn, 2004). One indication that key assumptions are met is when the sample attains ‘equilibrium’. This is the point at which the

sample distribution on key variables remains stable within 2% of the equilibrium distribution, even though more individuals enter into the sample (Heckathorn, 1997; 2002). It is at this point that the sample composition becomes independent of the seeds thereby overcoming biases introduced by the non-random selection of seeds. Therefore, it is after the point of equilibrium that the sample becomes representative (Salganik, 2006). Sampling ends when the pre-calculated sample size is reached. In addition to pre-existing social trust between recruiters and recruits, RDS uses a dual system of structured incentives whereby participants are paid for participating in a study and for recruiting their peers into the study.

Because hard to reach populations often have no sampling frame, RDS uses each participant's social network size to set up the probability of selection. Network sizes are measured by asking all participants to recall how many peers they know and have seen during a set period of time (e.g., one month). Network sizes are an essential part of RDS data analysis as they are used to weight the sample data to compensate for the over-sampling of participants who have larger average network sizes and who thus have more recruitment paths leading to them (Heckathorn, 1997; 2002). In addition, RDS requires additional analytical steps which take into account a combination of differential recruitment effectiveness across groups (Heckathorn, 1997; 2002). Differential recruitment is assessed by collecting data on who recruits whom.

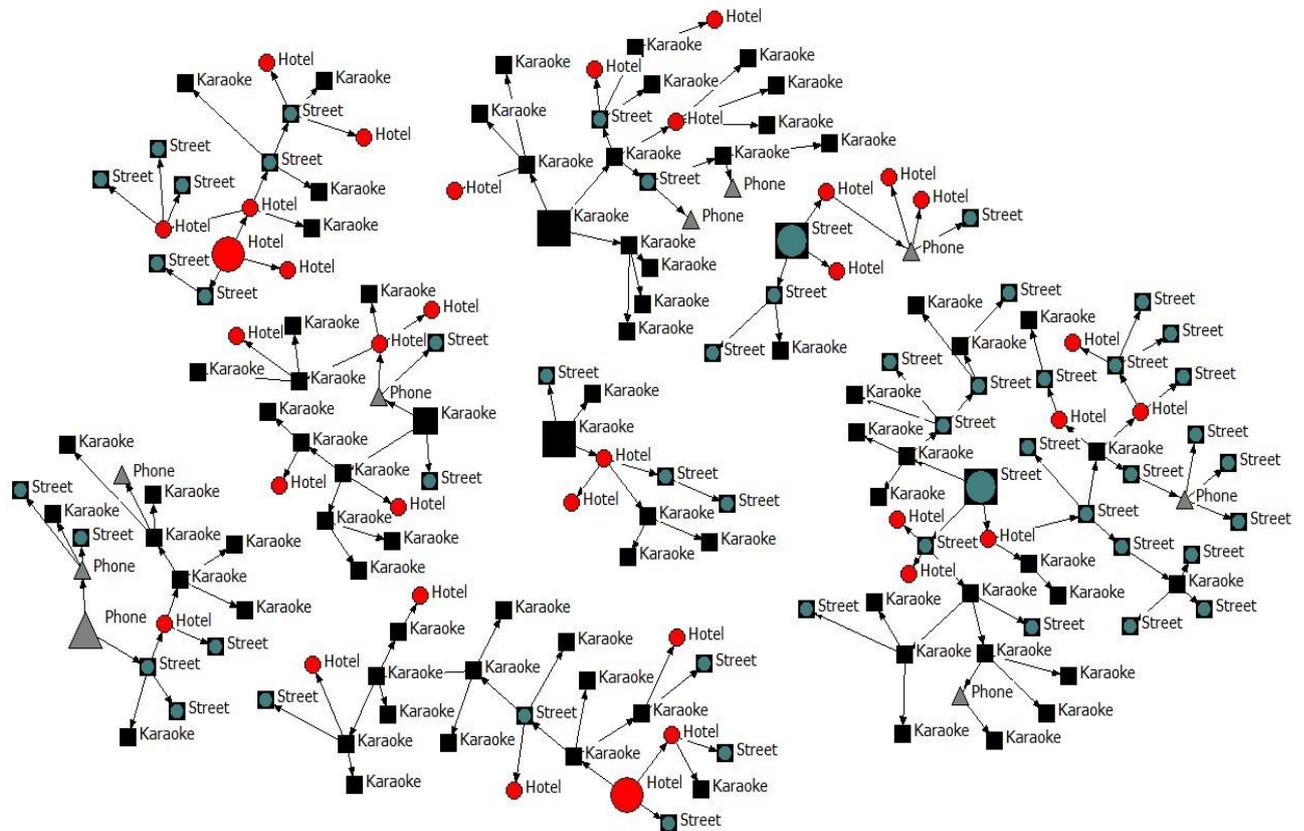
RDS requires rigorous adherence to implementation and analysis requirements which are sometimes ignored resulting in studies claiming to use RDS when in fact they are merely snowball samples (Johnston et al, 2008). This paper reviews the major elements involved in implementing RDS among hard-to-reach populations at risk for HIV. In addition, we present common challenges to using RDS and provide recommendations. Finally, we present data from an RDS study to illustrate the differences between estimates derived via snowball sampling (i.e., RDS without weighting) and the RDS methodology.

## Overview

RDS uses a chain referral (i.e., snowball) methodology to collect data from hard-to-reach populations whose members form interlinked social networks. Several important RDS field and analytical components are presented below

### *Seeds*

RDS begins with a set of participants, or seeds, purposively selected from the target population. Seeds are treated as any other participant (i.e., screened, interviewed, etc.) and must meet the eligibility requirements set up at the outset of the study. In addition, seeds must have special attributes that will ensure effective recruitment. Seeds should have large social network sizes, be respected by members of the target population, be able to convince others to participate in the study and have some interest in the study goals (Heckathorn, 1997; 2002). In addition, seeds should comprise key sub-populations and characteristic diversity to increase 1) the possibility that the final sample forms one complete social network component and 2) the speed at which sample characteristics reach a stable composition (equilibrium) with respect to the traits upon which the research focuses (two essential assumptions for RDS methodology). For example, in many settings, FSWs may be separated by type (e.g., street vs. internet vs. brothel-based) into sub-networks among which communication and contact are limited. These 'cleavages' could impact recruitment across type, resulting in a sample of two or three distinct groups rather than one complete social network component. Figure 1 presents an example of eight well integrated recruitment chains of FSW types based on the question 'where do you most often solicit your clients?' In this example, FSWs of different types (street/park/port=circle within a box; hotel/guesthouse=circle; karaoke bar/restaurant/disco=square; and, agent/telephone/internet=triangle) are linked through their social networks and all types of FSWs were recruited within one of several recruitment chains independent of the seed type with which they started (seeds are represented with larger symbols).

**Figure 1. Recruitment graph from one seed in a sample of female sex workers<sup>1</sup>**

Seeds that comprise important characteristics will ensure that the sample reaches into all sub-networks of the target population. Ideally, formative assessment in advance of data collection will identify potential cleavages and assist in the selection of effective seeds.

### **Recruitment**

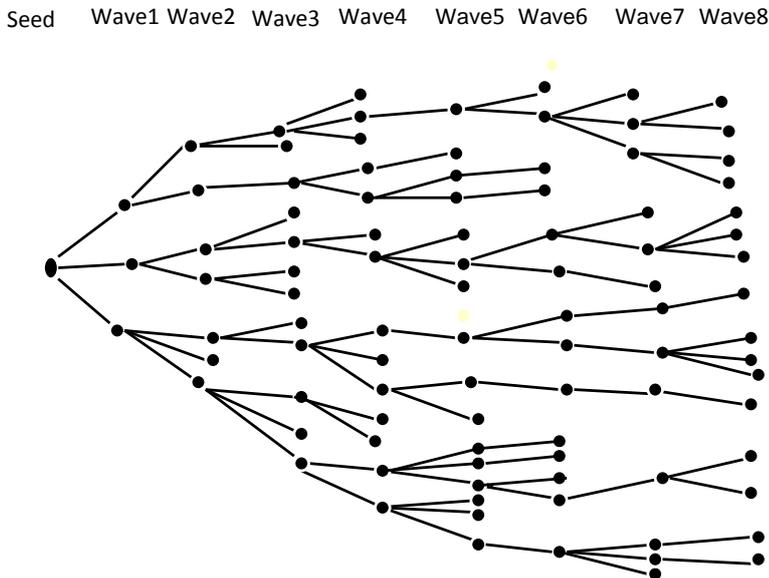
For recruitment to function, respondents must know one another as members of the target population. ‘Knowing’ someone involves general recognition allowing both acquaintances (weaker ties) and friends (stronger ties) to be recruited. The RDS recruitment strategy involves participants using a fixed number of uniquely coded coupons to recruit their peers from their social network. The seeds’ purported social influence among their peers and positive experiences during the survey process promote the uptake of coupons by their peers. After the seeds are interviewed, they become recruiters and are given a set number of coupons with which to recruit eligible peers from their social network to participate in the survey. Once each seed’s recruits have participated in the survey, they in turn are given a set number of coupons with which to recruit peers from their social networks to participate. This process results in the sample expanding, theoretically exponentially, from wave to wave to form a recruitment chain (figure 2). This process continues until the final sample is obtained.

An important assumption in the recruitment process is that recruitment occurs symmetrically (also known as reciprocal ties) so that any recruit, selected by a recruiter, would have been just as willing to recruit his or her recruiter if that person had not already participated in the survey. Process and analytical mechanisms should

<sup>1</sup> Street/park/port=circle within a box; hotel/guesthouse=circle; karaoke bar/restaurant/disco=square; and, agent/telephone/internet=triangle. Seeds are represented with larger symbols.

be established to prevent repeated participation in the survey. Biometric measurements and even fingerprints have been used to prevent repeated enrolment (Heckathorn, 2002; Heckathorn et al, 2006).

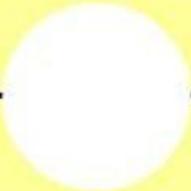
**Figure 2: Theoretical RDS recruitment chain**



### *Coupons*

The number of coupons distributed to participants is usually fixed (starting with three coupons) to allow all participants to recruit roughly the same number of peers. A coupon quota ensures that everyone has an equal chance to recruit peers. As illustrated in the coupon displayed in Figure 3, an important element is a space for a unique number to link survey results, biological results, and incentives and for tracking who recruits whom, essential for RDS analysis. Other elements illustrated in the display coupon are a non-stigmatizing title (Projecto Amaã means Project Soul in Portuguese), the address and/or a map (not shown here) of the site location, hours and days of enrollment, basic information about the study, and an expiration date to encourage steady recruitment and to discourage anyone enrolling after the study ends. Many coupons come in two parts: one part being that which is used by a recruiter to give to a recruit who in turn will use it to enroll in the study and another part used by a recruiter as a receipt for having recruited a peer. Coupons have been very fancy with elaborate designs and colors to very simple with information in black letters provided on white stock paper.

**Figure 3. Sample coupons for a survey in Manaus, Brazil.** (Courtesy of the Brazil Ministry of Health and Manaus survey team)

 <p><b>PROJETO AMAA</b> Ministério da Saúde </p> <p><b>Endereço:</b> Rua Taiqueirinha, Nº 57-Centro, (próximo ao ....)</p> <p><b>Fone:</b> ..... (você pode telefonar para agendar a entrevista)</p> <p>Este cupom é válido até: DD/MM/AAAA ID: <input type="text"/></p> <p>Horário de atendimento: <b>13:00 as 18:00h (de segunda a sexta)</b></p> <p>ESTE CUPOM DEVERÁ SER ENTREGUE NO DIA DA ENTREVISTA</p>	<p><b>CONVITE</b></p> <p>Você está sendo convidada a participar do Projeto: AMAA.</p> <p>Se você for "Batalhadora" na cidade de Manaus e tiver mais de 14 anos de idade, venha nos visitar e traga este cupom.</p> <p>Ele não pode estar rasgado, rasurado ou sem o número de identificação e a validade vencida.</p> <p><b>Venha nos conhecer, sua presença é importante!</b></p> 
<p><b>PROJETO AMAA</b></p> <p><b>Endereço:</b> Rua Taiqueirinha, Nº 57-Centro, (próximo ao ....)</p> <p><b>Fone:</b> ..... (você pode telefonar para agendar a entrevista)</p> <p>Este cupom é válido até: DD/MM/AAAA ID: <input type="text"/></p> <p>Horário de atendimento: <b>13:00 as 18:00h (de segunda a sexta)</b></p>	<p><b>PROJETO AMAA</b></p> <p>Traga este cupom após uma semana da data de vencimento.</p> <p>Ele não pode estar rasgado, rasurado ou sem o número de identificação.</p>

### *Incentives*

RDS relies on a variety of incentives to encourage participation. One incentive is mild ‘peer pressure’ by the recruiter to his or her peer. Another incentive may be the ability to receive HIV and other infection test results and treatment, something difficult to obtain in some countries where RDS is conducted and especially difficult for some populations who want to remain hidden from existing health care providers. A final incentive, also called ‘remuneration’, ‘transport fee’, ‘gift’ or ‘reimbursement’, is typically cash or items of monetary value. The final incentive often requires pre-survey qualitative research to ensure that one incentive is suitable to capture all sub-groups within the target population (Johnston et al, 2010). One difficulty about determining incentives is that if they are too high it could lead to the bartering or selling of coupons and encourage non-eligible persons to pretend to be part of the eligible population in order to enroll in the study and get the incentive. When incentives are too low, recruitment may be slow and, in some cases, attractive to only lower socio-economic, members of the population (Kendall et al, 2008). Both of these situations can lead to selection bias.

Most incentives used in RDS have been monetary. Creative alternatives to monetary incentives have included articles of clothing, cosmetics, phone cards, grocery vouchers and donations to charities.

### *Analytical procedures*

Correct analyses account for certain known biases found in most snowball sampling (Heckathorn, 1997). To this end, two essential pieces of data must be acquired during data collection: 1) the social network size of each participant; and, 2) connections between recruiters and their recruits. Social network size data are used to weight estimates to account for overrepresentation of those with larger social network sizes (ability to recruit more persons) and vice versa. Recruiter-recruit connections are used in a mathematical modeling of the recruitment process to generate relative inclusion probabilities (Heckathorn, 1997; 2002).

The study eligibility criteria are used to build the social network size question. To improve accuracy in responses to social network sizes it is useful to break the question into several parts. For instance, an MSM survey question can be broken up into three parts: 1) How many men who have anal sex with other men do you know by name and they know you by name and they live in [city of survey]?; 2) How many of those men are at least 18 years old?; 3) How many of those men have seen them in the past one month? Having a short time frame as used in question three will help to reduce recall bias.

When all methodological assumptions and analytical requirements are fulfilled, RDS yields estimates of population parameters from which inferences can be made about characteristics and behaviors of the sampled population (Heckathorn, 1997; 2002; Salganik & Heckathorn, 2004).

Because most participants are required to return to the interview site to collect an incentive for their success in recruiting others, RDS allows for these participants to provide data about the individuals who refused to accept a coupon from a recruit. These data can also be used to measure some level of non-response, or refusal to participate, rates. However, specific analytical procedures are needed to account for differential non-response in the results and such results will never provide an accurate picture of non-response. Typically, the response rate to the non-response instrument is low, thereby negating its use for adjustment to the analysis (authors' experience). However, the collected data may provide some insights that color the interpretation of the results.

### ***Why researchers use RDS***

The relatively sudden burst of data available on IDU, MSM and FSW from around the world in the past several years can be attributed in part to expanded resources and interest for such surveys and the advent of RDS. RDS offers a generally effective and efficient means to gather a probability sample from underserved and understudied populations and offers several reasons for being used widely.

- 1) Adequately sized samples of hard to reach populations can be obtained in a reasonable period for 'reasonable' costs.
- 2) Survey staff typically works from fixed sites where their physical security can be guarded (i.e., there is little street recruitment, an appealing consideration when sampling populations that may reside in dangerous neighborhoods).
- 3) Fixed sites facilitate conducting biological testing and relevant counseling and provision of other prevention, care and treatment services at the time of the survey.
- 4) Results may be generalisable to the larger population.

### ***Critical questions to ask before selecting RDS***

Some initial exploration of the population of interest can enhance the chance of selecting a proper sampling method. Like many other sampling methods, RDS does not work in every setting with every population. Tools are available to help make decisions on sampling methods and for determining whether RDS is the appropriate method given the target population and the geographic, cultural and social settings (Johnston et al, 2010; Université de Californie, San Francisco, 2009; Johnston, 2008; Johnston, Sabin & Prybylski, 2010). Generally, it is best to answer the following questions before choosing RDS for a survey. These can be answered using focus groups or key informant interviews.

**Table 2: Key questions to answer to determine if RDS is feasible**

Question	Type of response	
1) Is the population of interest socially networked?	If yes, continue	If no, select another sampling method
2) Does the population have social network sizes sufficient to maintain recruitment? That is, does the average population member have at least 3-5 peers, who would meet study eligibility criteria, who they could refer to the survey?	If yes, continue	If no, select another sampling method
3) Does the social network consist of one social network component?	If yes, conduct further formative research to determine if RDS is acceptable to the population	If no, ask question 4.
4) If the population does not consist of one social network component, are there some sub-network members that form ties with other sub-networks members?	If yes, conduct further formative research to determine if RDS is acceptable to the population and ensure that those who have connections across sub-networks are selected as seeds	

### *Accounting for biases in the data*

RDS is only a very good convenience snowball sample unless data are properly analysed. To illustrate this, table 3 below presents data on past month condom use among FSWs in Ho Chi Minh City, Vietnam. The RDS analysis tool (RDSAT) adjusted estimations for 'no condom use in the past month' is 38.8%, whereas the unadjusted estimation is 43.7%. This represents a 4.9% difference and indicates that had we not adjusted the estimates for potential biases past month condom use among FSWs would have been overestimated.

Sources of measurement error may be due to differential recruitment patterns or the higher level of homophily among FSWs using condoms in the past month. Network homophily is important to RDS in that it provides an indication of recruitment effectiveness among networks (Heckathorn, 1997; 2002). With a range between +1 (completely homophilous, i.e. exclusive preference for and recruitment from one's own group) and -1 (completely heterophilous, i.e. exclusive preference for and recruitment from outside of one's own group), homophily index values close to 0 suggest that social ties among recruits and recruiters cross networks, thereby overcoming biases that solely in- or out-group recruitment may have introduced. In table 3 FSWs who did not use condoms in the past month have a homophily of 25%; an indication of some restriction in recruitment by those FSWs who did not use condoms of those who did use condoms. Homophily provides a means to assess the level of bias and therefore the representativeness of the sample.

In addition, table 3 demonstrates some differentials in social network sizes resulting in some FSWs having a greater potential to recruit peers (likely with characteristics similar to them) resulting in an over or under representation of that characteristic (FSWs did not use condoms: 6.346=over representation; FSWs using condoms: 5.102=underrepresentation). The fact that category differences in homophily and network sizes in this sample for this variable are fairly minimal and that the population (adjusted) estimates approximate the sample (crude) estimates (e.g., the sample estimates fall within the confidence bounds of the population estimates) indicates that the sample without adjustment is fairly robust.

**Table 3 RDS estimation for past month condom use among FSWs**

	Did not use condoms	Used condoms	Total
Sex Risk (yes)			
Recruitment Count	91	77	178
Recruitment Proportion	.541	.458	
Sex Risk (No)			
Recruitment Count	83	147	230
Recruitment Proportion	.36	.639	
Total Distribution of Recruits	174	224	398
Estimated Network Size (adjusted)	6.346	5.102	
Homophily	.252	.069	
Crude estimate (no adjustment (excluding seeds))	.437	.563	1
RDSAT adjusted estimate*	.388	.612	1
Confidence intervals	.331, .447	.553, .669	
Standard errors	.058	.058	

\* RDSAT = Respondent Driven Sampling Analysis Tool; adjusted taking into account participants' personal social network sizes and who recruited whom.

### Ongoing Challenges

The rapid expansion of RDS use across countries and among multiple hard-to-reach populations comes with a cost. RDS is not a magic method to easily recruit previously understudied and inaccessible populations. On the surface, RDS receives praise for being easy to implement and successful at producing representative samples. However, numerous RDS surveys have been reported where social network size was inadvertently not collected or where recruiter-recruit connections were not tracked, resulting in the inability to produce accurate estimates. Proper RDS implementation requires adhering to numerous theoretical assumptions administered through a well-planned and rigorous protocol. In addition, the procedures to analyse RDS data are not easily understood and analysing data with RDSAT is challenging. When assumptions and analysis requirements are not met, the generalisability of a sample can be jeopardised. There are currently several published reports describing different challenges to RDS assumptions in implementation and analysis and possible solutions (Salganik, 2006; Johnston et al, 2008; Johnston et al, 2010; Johnston, Sabin & Prybylski, 2010; Malekinejad et al, 2008; Gile & Hancock, 2009).

## Conclusions

This paper describes the current use and some challenges associated with using RDS for measuring HIV prevalence and risk factors among hard-to-reach populations at risk for HIV transmission and acquisition.

RDS can provide externally valid (generalisable) data from hard-to-reach populations and has been used successfully to do so in an increasing number of international settings. However, RDS relies on a theoretical foundation that is still evolving and under debate by leading statisticians and methodologists. Many of the assumptions require further testing and refinement. Now that RDS has been utilised in several countries as the sampling method for routine BBSS, more evidence will arise to assess its level of accuracy in measuring HIV and risk behavior trends over time.

The importance of conducting detailed pre-surveillance field assessments to plan RDS surveys properly is vital and still underutilised. Qualitative data are critical to assess whether RDS is a suitable sampling method for a given country and context, to assess the target population's social network properties and to ensure the most appropriate logistical features (e.g., seed selection, hours and days of study operation, types of biological testing, acceptance by the community, etc.) (Johnston et al, 2010).

RDS has become an important tool for effectively measuring HIV and other infections prevalence and associated risk behaviors affecting hard-to-reach populations. RDS studies that are properly implemented and data that are properly analysed can provide extremely important and accurate findings to support cost effective and effective targeted prevention, intervention and treatment programs. Furthermore, future surveys collecting comparable data using RDS can be easily implemented based on an initial successful use of RDS. Although RDS has gained widespread popularity since its introduction, it is essential that researchers understand and follow the key assumptions and requirements presented within this paper and in the references cited.

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