Using Local Longitudinal Records to Estimate Transient and Resident Homeless Populations

Douglas L. Anderton
University of Massachusetts—Amherst

Abstract

Many local agencies that provide services to the homeless have only limited data and resources to estimate the extent of need or the size of the local population at risk of requiring the services they provide. Methods exist, however, that are capable of providing reasonable estimates of underlying service populations with minimal record keeping. In this paper one group of such models, first-capture models, is discussed as a resource-efficient technique for estimating the underlying population consistently at risk ("residents") and those occasionally at risk ("transients") of requiring agency services.

Introduction

Many service organizations and government agencies keep records of the services they provide to clients. Most often the various record-keeping systems employed by such agencies have evolved in response to organization-specific requirements for management and accountability. The form and content of such records are as varied as the organizations that maintain them. The purposes of this paper are twofold. First, it will demonstrate how such varied record-keeping systems may be used, after the fact, to estimate the local populations underlying, or generating, recorded client contacts. Second, an exploration of the potential for retroactive estimation of underlying populations through client contact records can suggest standard improvements in such records that may facilitate their use for such estimates.

There are many different approaches to, and interests in, the problems of estimating homeless populations. The estimation of local populations that rely upon an organization's services is, of course, a problem distinct from that of large-scale regional or national estimates of populations and their potential demand for services. The different levels of estimates that may be required for policy and management purposes are considered complementary rather than alternative choices. Nonetheless, the strategies explored in this paper are consistent with other recommendations to estimate both seen and unseen components of local populations in need, with minimal expense, by exploiting existing data resources.[1] The models discussed, however, are intended for pragmatic use by local service organizations and do not replace efforts to estimate national or regional homeless populations with some degree of precision.

Service population estimates from capture data

Any recorded encounter with a service agency that identifies an individual client as seeking, or requiring, services at a specific point in time is referred to as a "capture" of the individual. Several methods or models are available to estimate local populations served by an agency from such recorded individual encounters with the agency. The service population of such an agency, however, includes not only those individuals actually seeking agency services in any particular period of time, but also those individuals who may not seek services at that time but nonetheless have some potential, or risk, of requiring services from the agency over the same period of time. Capture models provide estimates of such underlying service populations at risk of capture or in potential need of services, whether actually seen or unseen by the agency, over any particular period of time. The task faced by capture models is thus one of determining some way of using available information from recorded contacts to estimate the underlying service population that generated the recorded client contacts by some of its members. Among capture models that address this common task, two broad classes of models may be distinguished, largely in terms of the type of information that is presumed to be available in the recorded client contacts.

First, in many cases, clients may be longitudinally observed or repeatedly surveyed, with the opportunity to observe a significant proportion of the population through repeated client contacts or captures. In these cases, it is possible to compare client populations captured in a first contact with those *independently* recaptured at a subsequent point in time to estimate the probabilities of capture and thus the size of the underlying population, including those not captured.[2] In human populations the requirement that the two captures be independent of each other can be questioned. In client services provided by agencies, it may be far more likely that services provided at one point in time might affect the likelihood that future services will be required. Wolter provides several alternative capture-recapture models that relax this frequently untenable assumption of independence.[3] Wolter's extensions to the basic capture-recapture model include cases in which probabilities of recapture are affected by capture, differ across time, and differ across subgroups of the population. Despite Wolter's formulation of capture-recapture models under these relaxed assumptions, their use in an applied setting requires both an a priori judgment as to the specific departures from independence to be accommodated, and the assumption that a significant proportion of the population will be subject to both capture and recapture.[4]

Second, in many other cases, it may be presumed that the probability of capture is relatively small in any reasonable interval of observation and that the probability of subsequent recapture is significantly affected by an initial capture. Medical, employment, retraining, and counseling services are all potentially such cases. In all such cases, an initial provision of services may significantly affect the subsequent need for further services. In addition, any situation in which researchers want to estimate an underlying service population before a significant proportion of the population might be recaptured also qualifies as such a case. To address such situations, researchers may use an alternative class of capture models based upon single contacts with clients. These first-capture models rely upon the distribution of times until capture to provide information about the probability of capture that is similar to the information provided by recaptures during a second interval.[5] Again, once the probability of capture has been estimated, an estimate of the underlying service population may be derived.

Capture-recapture models typically rely upon at least two distinct attempts to record the population, and require some assumption concerning the probabilities of capture within the two observations (usually independence). These models have, for example, become highly sophisticated in their application to repeated population censuses.[6] In contrast, first-capture models generally rely upon the longitudinal recording of captures over some period of time and require assumptions regarding the probability of capture over the interval of observation.[7]

Traps, first captures, and waiting times

Longitudinal observation through, for example, service logs may be called a "trapping mechanism" for the service population. This trapping mechanism records captures of individuals within the population over an arbitrarily selected duration of observation or study period. For the moment, it is presumed that the trapping mechanism also contains sufficient information to identify first captures. A "first capture" refers to the first recorded visit, or capture, of a specific individual within the study period. It does not refer to the first instance of a client's seeking services from a particular agency (unless it is also the first instance within the particular interval of observation selected).

Provided that dates and/or times of contact are recorded, the trapping mechanism, in turn, yields another source of information useful in estimating the probability of capture and the size of the underlying service population. The longitudinal trapping of first captures yields data on the "waiting time" until each such capture. Again, the waiting time refers to the time from the beginning of the selected period of observation until the client is first captured. It does not refer to the time the client began seeking such services, nor does it refer to the time since the client last sought such services.

If, for example, a research team selected March 15 through May 15 as its study period, then a client who was first seen during this interval on March 21 would have a waiting time to first capture of seven days (dated from March 15, the beginning of the study). Should the same client return for service in April, still during the study period, this visit is irrelevant because it is not a first capture. The fact that individuals may be more or less likely to return after their first capture during the study period is thus inconsequential. If, however, the same client had last been seen in, say, January and the probability that he or she would return during the study period is not independent of this prior visit, complications may arise. Discussion of such difficulties is deferred for the moment.

The distribution of the waiting times until first capture contains information on the probability that individuals will seek services and, therefore, on the size of the underlying service population. As in the case of capture-recapture models, further assumptions regarding the probability of capture are required to make use of information contained in the waiting time of captures. The assumptions required in first-capture models, however, concern the probability of individuals' seeking services over the course of the study. In many cases, it may be possible to make reliable, albeit general, assumptions about the basic pattern of first capture in the service population. If, and only if, such assumptions are forthcoming, then it is possible to use the distribution of waiting times until first capture to estimate the probability of first capture and the population generating service contacts. In short, a specific first-capture model is defined by these basic assumptions detailing the risks of first capture.

Residents and transients—population subgroups

Risks of first capture may differ widely in different subgroups of the service population. This is most apparent in the case of individuals entering (i.e., left censored) or leaving (i.e., right censored) the service population during the course of the study period. Such individuals are at no risk prior to their entry into, and after their departure from, the service population. Such differences generally necessitate the definition of service population subgroups through the pattern of first-capture risks in each group.

Although somewhat heroic, such definitions of population components are generally broad and robust. The situation is roughly analogous to assuming a normal distribution as an approximation of underlying probability processes in many statistical tests. General characterizations of the patterns of first-capture risk among population subgroups are usually sufficient for reasonable empirical applications.

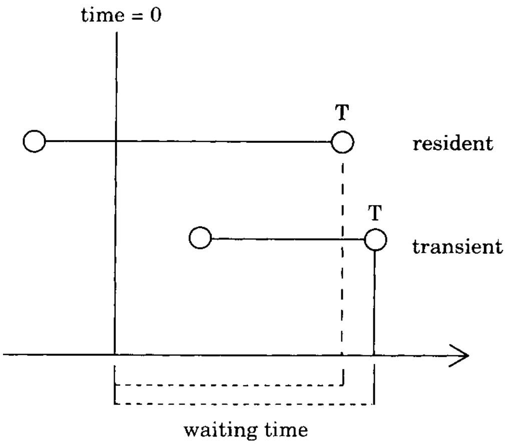
Prior applications of capture models have distinguished at least three population components—residents, transients, and the structurally excluded. Each of these subgroups is defined through the pattern of first-capture risks assumed. As a result, these terms are defined somewhat differently from their common usage in studies of the homeless.

"Residents," in the sense used by first-capture models, refers to individuals assumed to be at a sustained risk of contact or capture over the study period, rather than to individuals who necessarily reside in any geographic location. The two connotations are not entirely divorced; those with living quarters within a service area are more likely to be exposed to a sustained risk of capture. Nonetheless, it is important to remember the distinction when citing estimates of resident service populations.

The top solid line in figure 1 represents a resident individual entering the service population prior to the initiation of the study and at risk of capture until the recorded first capture or trap (labeled "T"). Again, note that the waiting time recorded is the time from the initiation of the study to the recorded first capture.

Not all individuals captured will be residents. Some captures will properly be regarded as transients from the standpoint of provision of services. "Transients," in the sense of first-capture models, are simply those individuals who enter the population or leave the population in such a way that they are subject to capture only during

Figure 1: **Illustration of Waiting Time for Transient and Resident First Captures**



some part of the study period. The lower solid line in figure 1 illustrates the case of a transient entering the service population after initiation of the study and remaining at risk until first capture (T). The waiting time recorded for the first capture is again measured from the initiation of the study and not from the entry of the individual into the service population.

Yet another population component is composed of individuals who, despite their standing as desired and deserving clients, are for a variety of reasons structurally excluded and not at any risk of capture. Capture models are, by definition, capable of estimating only components of the service population that are at some risk of a recorded encounter. Where structural impediments to contact are present within the capture mechanism, or within elements of the population itself, significant target populations may be isolated from services or contact and are thus properly reflected in estimation models as absent from the service population.

More elaborate applications of first-capture models have distinguished different types of residents or different types of transients, expanding the number of population components to be distinguished and estimated. In all applications, the distinction of such population components refers to the identification of subgroups that may have differing patterns in their risks of contact or recorded capture.

As defined in first-capture models, the resident population for a service organization consists of those individuals at continual risk of requiring such services as are provided over the course of study. The transient population consists of those individuals at risk of seeking services on a more intermittent basis than the resident population.

Manly's two-component example

Construction of a first-capture model consists of specifying probability distributions for the subgroups of the population with different risks of first capture. Manly's model[8] is perhaps the most straightforward first-capture model—the first-capture model applies to the present case of the homeless—with which to illustrate the process of formulating a specific model. This technical illustration may be skipped, but requires only a modest statistical background of those wishing a more detailed understanding of the models.

For residents, Manly's model relies upon a reasonable homogeneity assumption. He assumes that residents are subject to a constant fixed probability of being captured over the duration of observation. From this assumption, it follows that first-capture times would be expected to follow a simple negative exponential distribution. If θ is the single unknown parameter of this distribution, and capture times t are scaled to unity, then $\exp(-\theta t)$ is the probability that any one resident is not captured by time t, and by the time all observation is completed $[1-\exp(-\theta)]$ is the probability of capture. The distribution of first-capture times to be expected for resident captures is as follows:

$$f(t) = \frac{\theta e^{-\theta t}}{(1-e^{-\theta})} ,$$

with the first two noncentral moments given by

$$\mu_1(\theta) = \frac{1}{\theta} - \frac{e^{-\theta}}{(1-e^{-\theta})},$$

and

$$\mu_2(\theta) = \frac{2\mu_1(\theta)}{\theta} - \frac{e^{-\theta}}{(1-e^{-\theta})}.$$

Both the homogeneity assumption and the resulting distribution are extremely simple, robust, and generalizable.

Manly assumes that transients in and out of the trapping mechanism's reach over the course of study are equally likely to be captured at any point during the period of observation. From this assumption, transient first-capture times are expected to be uniformly distributed over the duration of the observation, with the first two noncentral moments simply equal to one-half and one-third, respectively (again assuming t is scaled to unity).

Manly then defines a second unknown model parameter p as the proportion of all recorded first captures who are residents. Equating the observed moments of the recorded first-capture times, m_1, and m_2, with those expected under the model assumptions,

$$m_1 = \hat{p}\mu_1(\hat{\theta}) + \frac{(1-\hat{p})}{2},$$

$$m_2 = \hat{p}\mu_2(\hat{\theta}) + \frac{(1-\hat{p})}{3},$$

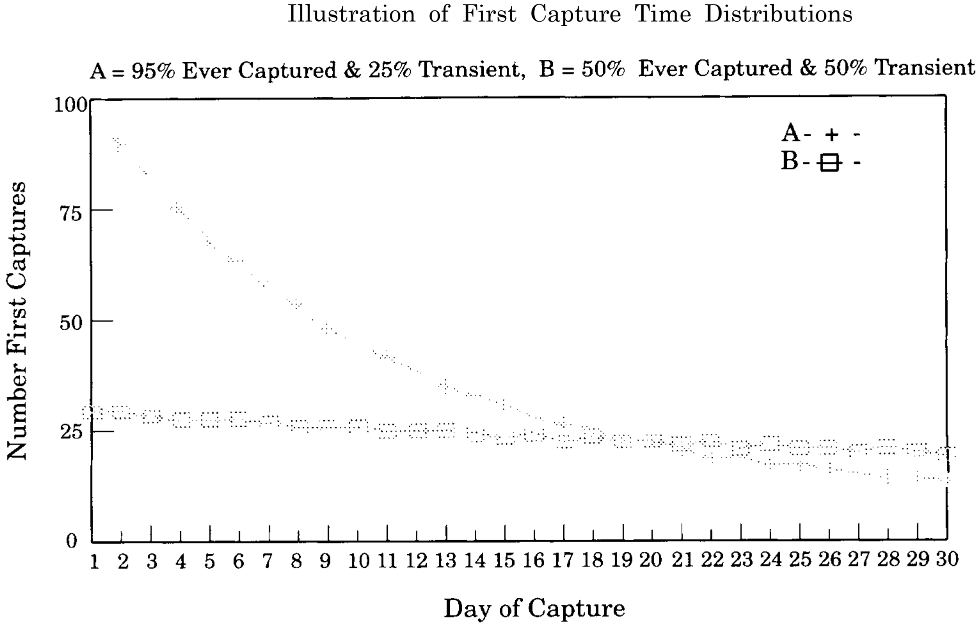
and the two unknown parameters are solved for through an iterative solution (i.e., the matching of moments method).[9]

Once the two model unknowns have been estimated, the underlying number of residents can be estimated as

$$\hat{R} = \frac{\hat{p}N}{1-e^{-\hat{\theta}}}$$

from the total number of first captures, N.[10]

Figure 2: **Hypothetical First-Capture Distributions**



Tabled solutions for θ, p, and R (along with their variances for use in computing standard errors) are provided for Manly's[11] specific model given the number of first captures, N, along with observed noncentral moments m_1, and m_2.

The manner in which the underlying probabilities of capture are reflected in the distribution of first-capture times may be illustrated with a simple graphical example. Figure 2 presents the distribution of first captures from an underlying resident population of 1,000, which would be expected from Manly's model for two hypothetical cases. The distribution of first captures labeled "A" illustrates the number of captures that would be expected each day if the probability of ever being captured were 95 percent (θ =3) over a 30-day study and 25 percent of captures were transients (p =.25). The distribution that is labeled"B" reflects a probability of ever being captured during the study of 50 percent (θ =.7) and of half of the captures being transients (p =.5). As the probability of capture increases, first captures are made earlier in the observation period. As the percentage of transient captures increases, the first captures are spread more uniformly throughout the observation period. It is this information in first-capture distributions that Manly's model uses to estimate parameters of the model.

Complex models and model assumptions

I have elaborated Manly's simple two-component model for three reasons. First, it is a very general, tractable, and widely applicable first-capture model. Second, it provides a simple illustration of how such models are constructed. Third, it illustrates the significance of the assumptions made concerning components of the service population.

One natural direction of extension for first-capture models is the incorporation of additional complex population subgroups. Anderton et al., for example, used first-capture models for human populations over a long observation period.[12] In their application, a third population component, that of permanent immigrants, was incorporated. Based on secondary data concerning the inflow of immigrants to the population, it was assumed that immigration was linearly increasing over time. Upon arrival, immigrants then experience the same probability of capture as residents.[13] This application illustrates the way simple population trends may be incorporated into a first-capture model. Other, more complex models are also feasible through subgroup definitions of capture probabilities. Osculatory (cyclical) terms for seasonal migrations into or out of a population may be accommodated similarly to immigrants.

First-capture models may also be extended in directions other than the addition of more complex subgroup definitions. There are two such notable directions of plausible development.

First, as Raftery et al. demonstrated, successive estimates of the population may be combined through Bayesian methods to achieve a more precise tracking of the population over time.[14] Second, in a manner similar to Nelson's elaboration of the Gamma-Poisson model,[15] it is plausible to combine (i.e., convolute) a distribution of heterogeneity (e.g., the gamma distribution) with first-capture distributions to allow for, and estimate the extent of, variation within population subgroups.

Although many more complex elaborations are possible, they are generally unnecessary for pragmatically useful, small-area estimates of service populations. Manly's[16] model, outlined above, should prove sufficient for many, if not most, envisioned applications to homeless service populations. The assumptions of a simple model should be questioned primarily when there are (1) significant trends in population components over the study period; (2) long study durations generating such complex trends; (3) significant internal heterogeneities in the probability of capture within the defined population components; or (4) extremely low capture probabilities over the study period.

In short, as with all estimation models, the assumptions of first-capture models are admitted simplifications of reality. The adequacy of these assumptions is generally not endangered by some departure from these assumptions. In any case, a test of the adequacy of the assumptions is readily forthcoming through comparison of the predicted (or fitted) distribution of first-capture times with the observed distribution of first-capture waiting times.

Geographic ambiguities in homeless service populations

Also as illustrated by the formulation of Manly's[17] model, the underlying service population is defined through the subgroup risks of first capture. Although not all clients need be captured through service contacts in any time period, only the population at risk of service contact is represented in the distribution of first captures. It is essential for meaningful use of first-capture models to remember that the population estimated by the model is an estimated population at risk of using organizational services.

The population at risk is not limited to a specific geographical region. Certainly, a (sometimes identifiable) majority of the underlying service population will correspond to the geographic vicinity of the service organization. However, the exact boundaries of a service area are not clearly delineated, and the population at risk also includes transient populations passing through the geographic area. Again, an estimate of the geographic boundaries of this transient population is beyond the capabilities of first-capture models, and these boundaries may vary widely from those of the resident population. *Ex post facto* information, collected at the time of service, on the original location of clients is merely indicative of the sample served. In short, first-capture models only estimate the populations at risk of service contact; they do not provide exact details as to the geographic locations of these populations.

Data collection requirements

One reason for exploring the use of first-capture models is the simple fact that many organizational record-keeping systems already contain the minimal information necessary for their use. Although some studies have employed such records in capture-recapture models, the emphasis on using such records for population estimates is relatively light in homelessness studies. Several reasons may explain the lack of reliance on service records. First, some service organizations keep no records of service or only crude records of client contact. Soup kitchens, for example, may see no need for such records and/or avoid record keeping out of respect for their clients' confidentiality and fear of intimidating them. Second, many homelessness studies rely either on scientific sampling designs to generalize estimates to national levels or on ethnographic methods to elucidate cultural aspects of the homeless. Finally, in homelessness research, as elsewhere, both the political economy of funded research and researchers' desires for autonomous control of the research agenda encourage primary data collection rather than maximal pragmatic use of existing data. In any case, service registers do exist for many organizations (e.g., shelters) that identify individual clients (commonly including even social security numbers) and services provided with sufficient precision to ascertain waiting times to first service contact in any period. Many other organizations could achieve such capabilities with a minimal record-keeping system or service register.

Figure 3 itemizes the basic data either necessary or desirable in records kept for first-capture modeling. In the simplest form

Figure 3: **Data Required and Recommended for First-Capture Modeling**

I. To identify first captures and waiting time to first service contact

(1) Unique individual identifier
(2) Date and/or time of service contact

II. An alternative to identify first captures and analyze trapping avoidance

(3) Date and/or time of last service contact

III. To assess differences in seeking services and estimate unique service populations by type of service

(4) Type of service this visit, and
(5) Date and/or time of last similar service

IV. To assess differences in seeking services and estimate unique service populations by type of client

(6) Other client characteristics/type of client

possible, the data necessary for first-capture models include only a unique individual identifier and the date and/or time of the service contact. Once a study period is selected, first captures can then be identified from such records as the first service visit by the individual after the beginning of the study period. Again, first capture refers only to the first visit within the study period, not to first visit ever. Waiting times for these first captures are then simply the times from the beginning date of the study period to the date of the service contact. It is not necessary to distinguish residents from transients. The proportion of first captures that are attributable to residents is estimated by the model.

The accuracy required in recording time of service depends on the unit of time inherent in the capture mechanism (e.g., nightly or daily shelter services, hourly medical appointments) and the length of observation. The joint influences on time accuracy required are the potential time unit of capture (e.g., daily, hourly) and some meaningfully precise division of time over the duration of the records used (e.g., days are sufficiently accurate if the study period is several weeks or months, but not if it is several days only).

Even though no further data are mandatory, additional data may significantly enhance the use of first-capture models. Most notably, information should be collected when possible on the date and/or at the time of last service contact. Reliability of the data may be verified through a sample comparison with the last recorded contacts. If reliable, this item fulfills two desirable functions. First, identifying first captures no longer requires matching records by unique identifiers over the study period. Second, individuals who visited the service agency prior to the study period (and the date of their prior visit) may be identified. The latter information is useful in assessing the assumptions of first-capture methods. As noted, these methods minimize sensitivity of capture probabilities to prior visits by relying only on first captures in the study period. However, in the case of ongoing service enterprises, capture probabilities may be sensitive to visits prior to the initiation of the study. Examining first-capture waiting-time distributions by time since last visit prior to the study may reveal (and aid in resolving) any significant sensitivity of capture probabilities due to prior capture (i.e., trap avoidance).[18]

Because first-capture models also presume some homogeneity or similarity in the probability of capture, it is also desirable to collect information relevant to this assumption. First, the agency may provide multiple types of services that individuals have different risks of seeking. In this case, there is theoretically a distinct service population corresponding to each type of service provided. The population should rightfully be estimated for each type of service, requiring data on the type of service provided at this visit, and where possible, the date and/or time of last similar service contact. Specific hypotheses of different capture probabilities or service populations by type of service may be tested through the model parameters representing the probability of capture (i.e., θs), the proportion/number of residents (i.e., p and R), and their standard errors.

Second, significant differences are likely to exist in the probabilities of seeking services according to characteristics of the clients themselves. Separate estimates for the service population of different types of clients may be explored for any specific characteristics desired if general information is collected on the client characteristics or type of client. Again, the hypothesis of differing capture probabilities may be explicitly tested for subgroups of clients to assess their differential use of services (i.e., the probability of capture). Although recorded contacts may represent predominantly one type of client, first-capture models may thus reveal that a different type of client is more predominant in the service population but less likely to seek agency services. If capture probabilities do not differ substantially, the different types of clients may be combined for more robust estimates.

These six types of data represent easily achieved data demands for longitudinal record keeping. If incorporated in ongoing service registers, they avoid the necessity of determining the beginning or length of the study period ahead of time, and thus the question of how long a period of observation is compatible with longitudinal first-capture models. A hard, fast answer to this question is not forthcoming out of context. Recent applications have ranged from hours[19] to decades.[20] As with all methods of statistical inference, either the trapping mechanism or the duration of observation must provide a sufficient sample size to give relatively small variance estimates.[21] Waiting-time methods are substantially robust against quota sampling in that the study period can be extended until sufficient cases are captured to achieve the desired variance of estimates. Of course, if ongoing service registers are used, it is possible simply to adjust the analysis period after the fact to the point at which estimates achieve the desired precision or newly recorded first captures taper off, or to a pragmatically desired period of reference for residents.

In agencies that already maintain record-keeping systems, these data demands may be easily accommodated. In those that do not currently maintain service records, a minimal implementation of these suggestions may provide a reasonable means for estimating and analyzing service populations for agencies currently forgoing the opportunity to do so. For example, soup kitchens without existing record systems might easily implement a daily sign-in sheet, recording only a name and/or date of last visit to the facility under the heading of the current date. Although some problems can be envisioned in collecting such information, the practice could yield tenable estimates of the local service population with minimal effort, cost, and discomfort.

Summary

First-capture models represent only one limited tool for population estimates in data-deficient settings. They do, however, provide a reasonable avenue for estimating service populations from existing or readily collected data. In their short history of application, first-capture models have proven reasonably reliable at a minimal cost. For purposes of tracking broad changes in component-population sizes, assessing potential service markets from pilot or limited programs, and making broad regional comparisons, they may provide an invaluable tool for small-area or local estimations of homeless service populations.

Of course, estimates from all capture models vary in their reliability as the model assumptions are more or less appropriate. Standard errors of parameters are available for inference and for judgment of the accuracy of model estimates. However, as with all statistical models, the estimated error variances of model estimates are themselves subject to the adequacy of the model's assumptions. Although capture model assumptions are general and substantially robust, estimates cannot be presumed to have an extremely high level of precision for application to complicated situations. Guidance as to the adequacy of model assumptions can best be found by comparing the observed and fitted distribution of first-capture times. The data that are recommended above for collection provide the information necessary to explore the adequacy of model assumptions within various subgroups of the service population.

Recognizing the potential of first-capture models may also have some beneficial consequences for records commonly kept by service agencies and those not kept by other agencies. Minor adjustments to record keeping or the implementation of minimal data collection may well provide a plausible administrative tool for estimating service populations and trends within that population over time. Minimal costs are required for such an enterprise, as is reflected in the modest data collection agenda of figure 3. Though this paper has suggested basic data that are useful in first-capture methods, a more general standardized format incorporating data desired within a particular type of service agency could easily be formulated. Such standardization might then allow some comparative analysis across agencies, regions, and so forth of a more broadly based service program. Once again, however, the primary strength of the models discussed is their ready adaptability to existing or minimal data resources.

Although estimates from the models discussed are clearly less precise than the results of a census or an exhaustive survey of a service population, a proper application may provide more than sufficient administrative detail. Exploring cost-effective uses of existing information through models such as those discussed may avert the desire, or perceived necessity, of local service organizations to replicate the methodologies of more extensive, and expensive, large-scale national studies. These models also provide a minimal alternative for those who resist more extensive data collection systems.

Author

Douglas L. Anderton is an associate professor in the Department of Sociology, University of Massachusetts—Amherst.

Endnotes

1. Richard P. Appelbaum, "Counting the Homeless" in *Homelessness in the United States: Data and Issues,* Jamshid Momeni, ed. (New York: Praeger, 1990) 1-16.

2. Charles D. Cowan and Donald Malec, "Capture-Recapture Models When Both Sources Have Clustered Observations," *Journal of the American Statistical Association* 82, no. 394 (1986): 347-53; P.A.P. Moren, "A Mathematical Theory of Animal Trapping," *Biometrika* 38 (1951): 307; C. Zippen, "An Evaluation of the Removal Method of Estimating Animal Populations," *Biometrics* 12 (1956): 163.

3. Kirk M. Wolter, "Some Coverage Error Models for Census Data," *Journal of the American Statistical Association* 81, no. 394 (1986): 338-46.

4. As Wolter notes (p. 341), biases will tend to be relatively small as the capture probabilities for individuals present during both capture intervals approach a certainty of capture.

5. Douglas L. Anderton, Joseph Conaty, and Thomas W. Pullum, "Population Estimates from Longitudinal Records in Otherwise Data-Deficient Settings," *Demography* 20, no. 3 (1983): 273-84; D.W. Hayne, "Two Methods for Estimating Populations from Trapping Records," *Journal of Mammalogy* 30 (1949): 399; R. H. MacArthur and A.T. MacArthur, "On the Use of Mist Nets for Population Studies of Birds," *Proceedings of the National Academy of Sciences* 71 (1974): 3230-3; B.F.J. Manly, "The Analysis of Trapping Records for Birds Trapped in Mist Nets," *Biometrics* 33 (1977): 404-10; J. Terborgh and J. Faaborg, "Turnover and Ecological Release in the Avifauna of Mona Island, Puerto Rico," *Auk* 90 (1973): 759-79.

6. Cowan and Malec; Wolter.

7. Manipulations of data have, of course, also been employed to recode longitudinal records into distinct periods of capture and recapture. Assumptions of independence are, obviously, more problematic in such efforts, although plausible or tractable in many cases.

8. Manly.

9. Maximum likelihood methods are in general more robust with exponential parameters and may be necessitated by more complex models than Manly's.

10. As the probability of capturing a resident increases to certainty, the number of underlying residents approaches simply the proportion of captures estimated to be residents. Also note that as the proportion of captures estimated to be residents approaches unity, the number of residents approaches the number of captures, inflated by the probability of capture.

11. Manly.

12. Anderton, Conaty, and Pullum.

13. Again, this population component has its own expected distribution of first-capture times and corresponding noncentral moments. Three observed moments are then required to solve for the three unknown parameters of the model (now including the proportion of immigrants).

14. Adrien E. Raftery, Judith E. Zeh, and Patricia A. Styer, "Bayes Empirical Estimation of Bowhead Whale, Balaena mysticetus, Population Size Based Upon the 1985 and 1986 Combined Visual and Acoustic Consensus off Point Barrow, Alaska" (Paper SC/40/PS6, presented to the International Whaling Commission Scientific Committee, June 1988).

15. James F. Nelson, "Multivariate Gamma-Poisson Models," *Journal of the American Statistical Association* 80, no. 392 (1985): 828-34.

16. Manly.

17. Ibid.

18. Of course, in the case of essentially one-time services repeat visitations present no difficulty. If trap avoidance is a difficulty, an additional population component can be specified for repeat visits, with the capture probability being a function of time since last visit. This is similar to Wolter's strategy in

capture-recapture models. In this case, the recommended data would become essential. Even when prior visits are not recorded it is sometimes possible to assess trap avoidance through subdividing the study interval and comparing waiting-time distributions in these subintervals for first-ever visits with repeat visits by duration since last visit.

19. Manly.

20. Anderton, Conaty, and Pullum.

21. For Manly's model, tables are provided from which an *a priori* judgment may be made as to required sample sizes, given a range of anticipated model parameters.