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Bibliography on Capture-Recapture Modelling With Application to Census Undercount Adjustment

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ABSTRACT

This article presents a selected annotated bibliography of the literature on capture-recapture (dual system) estimation of population size, on extensions to the basic methodology, and the application of these techniques in the context of census undercount estimation.

KEY WORDS: Capture-recapture; Census undercount; Dual system estimation; Loglinear models.

1. INTRODUCTION

The method of capture-recapture for estimating the size of a closed population has been in use since at least the nineteenth century, when Peterson (1896) developed the standard estimator that bears his name for the use with fish populations. Subsequent application to other types of populations include Geiger and Werner (1924) - physics; Lincoln (1930) - wildlife; Chandrasekar and Deming (1948) - vital statistics for human populations; Wittes and Sidel (1968), Wittes, Colton and Sidel (1974) - epidemiology; Sanathanan (1972b) - particle scanning in physics; Blumenthal and Marcus (1975) - life testing; Green and Stollmack (1981),Rossmo and Routledge (1990) - crimes and criminals. In the context of the study of human populations and demography the method is often referred to as dual system estimation. We have included virtually no references to the related problem of counting the number of species, which goes back to the work of R.A. Fisher in the 1940s and had an elegant formulation in Efron and Thisted's (1976) *Biometrika* paper on "How many words did Shakespeare know?".

The basic capture-recapture approach rests on a number of assumptions, *e.g.*: (1) the population under study is closed; (2) individuals (units) can be perfectly matched from capture to recapture; (3) capture probabilities are constant across the individuals (units) in the population; (4) the probability of inclusion of an individual (unit) in recapture sample is independent of inclusion in original census or sample. Beginning in the late 1930s various investigators began to explore extensions that allowed for departures from the assumptions. These methods typically require additional data such as a second recapture (or even a third) and the full capture-recapture history of each individual.

For human populations and the study of vital statistics the methodology has long been linked to census data, *e.g.*, see Tracy (1941) and Shapiro (1949, 1954). In connection with the 1950 decennial census of population, the U.S. Bureau of the Census introduced the use of a sample matched to the census records for coverage evaluation. This approach has evolved into what is currently known as the Post Enumeration Survey approach to undercount and overcount estimation, and it has been the focal point of the recent and ongoing controversy of the possible adjustment of the 1980 and 1990 censuses, *e.g.*, see Eriksen and Kadane (1985); Freedman and Navidi (1986, 1992); Freedman (1991); Wolter (1991).

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This selected annotated bibliography presents an overview of published literature on capture-recapture estimation of population totals. It includes historical references, articles that explore departures from assumptions and extensions of the basic methodology, and is most complete in connection with papers that describe the dual and multiple system approaches in the context of census undercount estimation. In this regard, however, we have not included references to any of the unpublished memoranda and papers from the U.S. Bureau of the Census (primarily because most of these have been replicated in some form in the published literature). We have tended to exclude articles published in unrefereed proceedings for related reasons. Because the literature on specialized applications of capture-recapture techniques to wildlife populations is so extensive, and only some of it is of relevance for human populations, we have provided primarily references to reviews of this literature, *e.g.*, see Brownie *et al.* (1977); Otis *et al.* (1978); Seber (1973, 1982). Similarly we have included only a small number of references to the more specialized methods in use for life testing, *e.g.*, see Dahiya and Blumenthal (1986), as well as those in use for software reliability applications, *e.g.* Jelinski and Moranda (1972), and Duran and Wiorkowski (1981). The methods in this latter literature diverge in significant ways from those used in the basic capture-recapture and dual system approaches.

2. SELECTED BIBLIOGRAPHY

ALHO, J.M. (1990). Logistic regression in capture-recapture models. *Biometrics*, 46, 623-635.

- Extends usual dual systems approach to allow for multiplicative stratification effects.

BAKER, S. G. (1990). A simple EM algorithm for capture-recapture data with categorical covariates (with discussion). *Biometrics*, 46, 1193-1200.

- Links cross-classification of covariates to the capture and recapture via loglinear models and then uses EM algorithm to estimate population size.

BIEMER, P.P. (1988). Modelling matching error and its effect on estimates of census coverage error. *Survey Methodology*, 14, 117-134.

- Develops models for evaluating impact of matching error on census coverage.

BISHOP, Y.M.M., FIENBERG, S.E., and HOLLAND, P.H. (1975). *Discrete Multivariate Analysis: Theory and Practice*, Chapter 6. Cambridge, MA: MIT Press.

- Monograph on loglinear models which includes a chapter on the relationship to capture-recapture models.

BLUMENTHAL, S., and MARCUS, R. (1975). Estimating population size with exponential failure. *Journal of the American Statistical Association*, 70, 913-922.

- Uses exponential distribution to estimate population size based on a subset of observations obtained by truncated sampling.

BOSWELL, M.T., BURNHAM, K.P., and PATIL, G. P. (1988). Role and use of composite sampling and capture-recapture sampling in ecological studies. In *Handbook of Statistics 6: Sampling*, (Eds. P.R. Krishnaiah and C.R. Rao). Amsterdam: North Holland, 469-488.

- Gives succinct summary of several basic variants on capture-recapture models and their estimation.

BROWNIE, C., ANDERSON, D.R., BURNHAM, K.P., and ROBSON, D.S. (1977). Statistical inference from band recovery data: a handbook. *U.S. Fisheries and Wildlife Service Resource Publication No. 131.*

- Describes a comprehensive range of capture-recapture models and appropriate goodness-of-fit tests, with emphasis on banding experiments.

BURGESS, R.D. (1988). Evaluation of reverse record check estimates of undercoverage in the Canadian Census of Population. *Survey Methodology*, 14, 137-156.

- Describes the survey-based accounting approach of the reverse record check for undercount estimation. Does not deal with issue of exclusion of individuals from census and other lists.

BURNHAM, K. P., ANDERSON, D.R., WHITE, G.C., BROWNIE, C., and POLLOCK,K.H. (1987). *Design and Analysis Methods for Fish Survival Experiments Based on Release-Recapture*. Bethesda, MD: American Fisheries Society.

- Combines methodology of Brownie *et al.* for band recovery with survival estimation under Jolly-Seber mark-recapture models.

BURNHAM, K.P., and OVERTON, W.S. (1978). Estimation of the size of a closed population when the capture probabilities vary among animals. *Biometrika*, 65, 625-633. Correction (1981) 68, 345.

- Develops a capture-recapture model with heterogeneity for animals but constant probabilities of capture across samples. Model induces dependencies amongst captures.

CASTELDINE, B.J. (1981). A Bayesian analysis of multiple-recapture sampling for a closed population. *Biometrika*, 67, 197-210.

- Develops a Bayesian approach using beta priors for traditional independence-based Schnabel census model for multiple recapture data.

CHAKRABORTY, P.N. (1963). On a method of estimating birth and death rates from several agencies. *Calcutta Statistical Association, Bulletin*, 12, 106-112.

- Extends Chandrasekar-Deming approach to three or more sources.

CHANDRASEKAR, C., and DEMING, W.E. (1949). On a method of estimating birth and death rates and the extent of registration. *Journal of the American Statistical Association*, 44, 101-115.

- Develops dual-system technique and suggests the use of stratification for eliminating heterogeneity. Applies approach to estimation of number of births and deaths in several Indian villages.

CHAO, A. (1987). Estimating the population size for capture-recapture data with unequal catch ability. *Biometrics*, 43, 783-791.

- Explores heterogeneous catchability model of Burnham and Overton using a moment inequality to get a lower bound on population size.

CHAO, A. (1989). Estimating population size for sparse data in capture-recapture experiments. *Biometrics*, 45, 427-438.

- Explores adequacy of estimator resulting from moment inequality for heterogeneous catchability model in settings involving sparse data.

CHAPMAN, D.G. (1951). Some properties of the hypergeometric distribution with applications to zoological sample censuses. *University of California Publications in Statistics*, 1, 131-160.

- Develops the hypergeometric sampling model for estimating the population size in capture-recapture studies.

CHOI, C.Y., STEEL, D.G., and SKINNER, T.J. (1988). Adjusting the 1986 Australian census count for under enumeration. *Survey Methodology*, 14, 173-189.

- Describes the use of dual system estimation and a post enumeration survey to adjust the results of the Australian census. Also applies Wolter sex-ratio technique to check on sensitivity of dual system estimator.

CHRISTENSEN, H.T. (1958). The method of record linkage applied to family data. *Marriage and Family Living*, 20, 38-43.

CITRO, C. F., and COHEN, M. L., (Eds.) (1985). *The Bicentennial Census. New Directions for Methodology* in 1990. Washington, DC: National Academy Press.

- Report of a panel of the Committee on National Statistics on census methodology including an examination of the dual systems approach to undercount correction.

COALE, A.J. (1961). The design of an experimental procedure for obtaining accurate vital statistics. *International Population Conference*, New York, 372-375.

- Proposes the use of two lists covering the same sample from a population.

COHEN, M.L. (1990). Adjustment and reapportionment - analyzing the 1980 decision. *Journal of Official Statistics*, 6, 241-250.

- Examines effect of bias and variability on accuracy of adjusted and unadjusted census counts and the impact on the reapportionment of the U.S. House of Representatives.

CORMACK, R. M. (1981). Loglinear models for capture-recapture experiments on open populations. In *The Mathematical Theory of the Dynamics of Biological Populations*, II (Eds. R.W. Hiorns and D. Cooke). London: Academic Press, 217-235.

- Introduces Poisson model for capture-recapture and uses it with loglinear models to extend standard approach to allow for birth, death, and trap dependency.

CORMACK, R. M. (1989). Log-linear models for capture-recapture. *Biometrics*, 45, 395-413.

- Uses Poisson model and loglinear representation for inclusion of birth, death, and trap dependency into standard capture-recapture approach.

CORMACK, R. M., and JUPP, P.E. (1991). Inference for Poisson and multinomial models for capture recapture experiments. *Biometrika*, 78, 911-916.

- Compares MLEs of parameters under the two models and presents relationship between the corresponding asymptotic variances and covariances.

COWAN, C.D., and MALEC, D.J. (1986). Capture-recapture models when both sources have clustered observations. *Journal of the American Statistical Association*, 81, 347-353.

- Extends dual systems approach to situation involving clustered observations as in the U.S. census coverage improvement program.

CRESSIE, N. (1988). When are census counts improved by adjustment? *Survey Methodology*, 14, 191-208.

- Proposes a PES-based model for undercount adjustment utilizing an empirical Bayes estimation scheme and a family of loss functions.

CRESSIE, N. (1989). Empirical Bayes estimation of undercount in the decennial census. *Journal of the American Statistical Association*, 84, 1033-1044.

- Develops and applies empirical Bayes smoothing methods for census adjustment factors produced from dual systems approach for geographic by demographic stratification. Applies approach to state data from 1980 U.S. census.

CRESSIE, N., and DAJANI, A. (1991). Empirical Bayes estimation of U.S.undercount based on artificial populations. *Journal of Official Statistics*, 7, 57-67.

- Shows that synthetic estimation approach used by Isaki *et al.* is special case of empirical Bayes.

CROXFORD, A.A. (1968). Record linkage in education. In *Record Linkage in Medicine* (Ed. E.D. Acheson). London: E. and S. Livingstone, 351-356.

DAHIYA, R.C., and BLUMENTHAL, S. (1986). Population or sample size estimation. In *Encyclopedia of Statistical Sciences*, (Volume 7), (Eds. S. Kotz and N.L. Johnson). New York: Wiley, 100-110.

- Reviews theory underlying population size estimation from truncated sampling for discrete distributions and provides references to domains of application.

DARROCH, J.N. (1958). The multiple-recapture census I: Estimation of a closed population. *Biometrika*, 45, 343-359.

- Describes the maximum likelihood approach to the multiple recapture problem under complete independence.

DARROCH, J.N. (1959). The multiple-recapture census II: Estimation when there is immigration or death. *Biometrika*, 46, 336-351.

- Extends the maximum likelihood approach under independence to open populations with either immigration or death.

DARROCH, J.N. (1961). The two sample capture-recapture census when tagging and sampling are stratified. *Biometrika*, 45, 343-359.

- Extends the maximum likelihood approach with independence to the situation where the original captured individuals are stratified into s groups and the individuals in the recapture sample are stratified, but according to t (possibly different) strata.

DARROCH, J.N., FIENBERG, S.E., GLONEK, G.F.V., and JUNKER, B.W. (1992). A three-sample multiple-recapture approach to census population estimation with heterogeneous catchability. Submitted for publication.

- Extends triple system estimation to allow for individual heterogeneity and selected forms of dependence. Applies estimators to triple system data from census dress rehearsal in St. Louis.

DARROCH, J.N., and RATCLIFF, D. (1980). A note on capture-recapture estimation. *Biometrics*, 36, 149-153.

- Presents an alternative estimator for capture-recapture problems with interesting asymptotic properties.

DASGUPTA, P. (1964). On the estimation of the total number of events and of the probabilities of detecting an event from information supplied by several agencies. *Calcutta Statistical Association, Bulletin*, 13, 89-100.

- Extends Chandrasekar-Deming approach to three or more sources.

DAVIDSON, L. (1962). Retrieval of misspelled names in an airline passenger record system. *Communications of the Association of Computer Machinery*, 5, 169-171.

DEMING, W.E., and KEYFITZ, N. (1967). Theory of surveys to estimate total populations. In *Proceedings of the World Population Conference*, Belgrade, 1965 (Vol. 3). New York: United Nations, 141-144.

- Extends of Chandrasekar-Deming approach to three sources.

DIFFENDAL, G. (1988). The 1986 test of adjustment related operations in Central Los Angeles County. *Survey Methodology*, 14, 71-86.

- Describes implementation of post-enumeration survey approach to dual system estimation in a test census.

DING, Y. (1990). Capture-Recapture Census with Uncertain Matching. Ph.D. dissertation, Department of Statistics, Carnegie Mellon University.

- Develops a probabilistic matching model for use with dual and multiple system estimation, and considers a Bayesian approach for estimating the population size. Illustrates techniques using data from test census results from Los Angeles.

DING, Y., and FIENBERG, S.E. (1992). Estimating population and census undercount in the presence of matching error. Submitted for publication.

- Develops a probabilistic matching model for use with dual system estimation and illustrates its application to data from test census results from Los Angeles.

DURAN, J.W., and WIORKOWSKI, J.J. (1981). Capture-recapture sampling for estimating software error content. *IEEE Systems Engineering*, 7, 147-148.

EFRON, B., and THISTED, R.A. (1976).Estimating the number of unseen species: How many words did Shakespeare know? *Biometrika*, 63, 435-467.

- Adapts a parametric model due to Fisher and a nonparametric model for the classical species problem using empirical Bayes methods. Applies approach to the vocabulary of Shakespeare.

EL-KHORAZATY, M.N., IMREY, P.B., KOCH, G.G., and WELLS, H.B. (1977). Estimating the total number of events with data from multiple record systems: a review of methodological strategies. *International Statistical Review*, 45, 129-157.

- Review of literature and methods for dual- and multiple systems estimation. Includes sections comparing use of techniques and departures from assumptions in wildlife and human populations.

ERICKSEN, E.P., and KADANE, J.B. (1985). Estimating the population in a census year: 1980 and beyond (with discussion). *Journal of the American Statistical Association*, 80, 98-131.

- Applies dual system approach to 1980 census data, including the regression-based smoothing of undercount estimates and the estimation of adjusted odds ratios using demographic estimates.

ERICKSEN, E.P., KADANE, J.B., and TUKEY, J.W. (1989). Adjusting the 1980 census of population and housing. *Journal of the American Statistical Association*, 84,927-944.

- Presents revisions and extensions to the Ericksen and Kadane methodology and a critique of Freedman and Navidi.

FAY, R. E., PASSEL, J. S., ROBINSON, J. G., and COWAN, C. D. (1988). *The Coverage of Population in the 1980 Census*. Bureau of the Census. Washington, DC: U. S. Department of Commerce.

- Official Bureau of the Census report on attempts to measure undercount in the 1980 U.S. decennial census.

FEIN, D.J., and WEST, K.K. (1988). The sources of census undercount: Findings from the 1986 Los Angeles Test Census. *Survey Methodology*, 14, 223-240.

- Attempts to test hypotheses regarding the causes of census undercount for a hard-to-enumerate Hispanic urban population.

FIENBERG, S.E. (1972). The multiple-recapture census for closed populations and the 2^k incomplete contingency table. *Biometrika*, 59, 591-603.

- Introduces a method for estimating dependencies among multiple lists using loglinear models and develops a general approach for estimation using results on 2^k incomplete contingency tables and conditional estimation.

FIENBERG, S.E. (1989). Undercount in the U.S. decennial census. In *Encyclopedia of Statistical Sciences*, (Supplemental Volume), (Eds. S. Kotz and N.L. Johnson). New York: Wiley, 181-185.

- Presents historical background on the differential undercount of the U.S. population and brief descriptions of demographic analysis and the dual system estimation approaches.

FREEDMAN, D. A. (1991). Policy forum: Adjusting the 1990 census. *Science*, 252, 1233-1236.

- Critique of dual systems approach to adjustment of the 1990 census.

FREEDMAN, D.A., and NAVIDI, W.C. (1986). Regression models and adjusting the 1980 census (with discussion). *Statistical Science*, 1, 3-39.

- Critique of Ericksen and Kadane dual systems methodology as applied to 1980 census data.

FREEDMAN, D.A., and NAVIDI, W.C. (1992). Should we have adjusted the census of 1980? (with discussion). *Survey Methodology*, this issue.

- Continues critique of the use of dual system estimation and synthetic adjustment as applied to 1980 census.

GARTHWAITE, P.H., and BUCKLAND, S.T. (1990). Analysis of multiple-recapture census by computing conditional probabilities. *Biometrics*, 46, 231-238.

- Uses a recursive relationship to generate point and interval estimate for multiple-recapture census under independence.

GEIGER, H., and WERNER, A. (1924). Die Zahl der ion radium ausgesandsen a-Teilchen. *Zeitschrift für Physik*, 21, 187-203.

- Applies a capture-recapture method to radium ion particle detection estimation.

GOLDBERG, J.D., and WITTES, J.T. (1978). The estimation of false negatives in medical screening. *Biometrics*, 34, 77-86.

- Applies capture-recapture models to problems in medical screening.

GOUDIE, I. B. J. (1990). A likelihood-based stopping rule for recapture debugging software reliability. *Biometrika*, 77, 203-206.

GREEN, M.A., and STOLLMACK, S. (1981). Estimating the number of criminals. In *Models in Quantitative Criminology*, (Ed. J.A. Fox). New York: Academic Press, 1-24.

GREENFIELD, C.C. (1975). On the estimation of a missing cell in a 2×2 contingency table. *Journal of the Royal Statistical Society*, Series A, 138, 51-61.

- Introduces a non-zero value for the response correlation, by taking the mid-point of the range of permissible correlation values, and consequently derives a value for missing cell. Applies approach to census data from Malawi.

GREENFIELD, C.C. (1976). A revised procedure for dual record systems in estimating vital events. *Journal of the Royal Statistical Society*, Series A, 139, 389-401

- Applies bounds on correlation in a 2×2 table to dual system estimation in the presence of event correlation induced by heterogeneity.

GREENFIELD, C.C., and TAM, S.M. (1976). A simple approximation for the upper limit to the value of a missing cell in a 2×2 contingency table. *Journal of the Royal Statistical Society*, Series A, 139, 96-103.

- Uses approximation for upper bound for response correlation to derive an upper bound for missing cell.

HOGAN, H., and WOLTER, K.M. (1988). Measuring accuracy in a post-enumeration survey. *Survey Methodology*, 14, 99-116.

- Reports on Los Angeles Test of Adjustment Related Operations and estimates of sources of bias in post enumeration survey and census-based dual systems estimates.

HOLST, L. (1973). Some limit theorems with applications in sampling theory. *Annals of Statistics*, 1, 644-658.

- Applies results on successive sampling to derive asymptotic distribution of usual Peterson estimator when there are heterogeneous capture probabilities or the effects of matching.

HOOK, E., and REGAL R. (1982). Validity of Bernoulli census, log-linear, and truncated binomial models for correcting underestimates in prevalence studies. *American Journal of Epidemiology*, 116, 168-176.

- Applies different loglinear related methods used to study the number of infants born with Downs syndrome.

HUGGINS, R.M. (1989). On the statistical analysis of capture experiments. *Biometrika*, 76, 133-140.

- Uses linear logistic models for capture probabilities for individuals and capture occasions.

HUGGINS, R.M. (1991). Some practical aspects of a conditional likelihood approach to capture experiments. *Biometrics*, 47, 725-732.

- Uses linear logistic models for capture probabilities and exploits temporal order of captures to introduce dependence amongst captures and on measurable covariates for those captured at least once.

ISAKI, C.T. (1986). Bias of the dual system estimator and some alternatives. *Communications in Statistics, Theory and Methods*, 15, 1435-1450.

- Exploits upper bound on correlation bias to reduce the bias of the dual system estimator.

ISAKI, C.T., and SCHULTZ, L.K. (1986). Dual system estimation using demographic analysis data. *Journal of Official Statistics*, 2, 169-179.

- Uses demographic analysis data to get revised dual system estimates for 1980 census using different models for correlation bias.

ISAKI, C.T., and SCHULTZ, L.K. (1987). The effect of correlation and matching error in dual system estimation. *Communications in Statistics, Theory and Methods*, 16, 2405-2427.

- Develops a simple matching error model in the presence of correlation bias to compare three dual system estimators.

ISAKI, C.T. , SCHULTZ, L.K., DIFFENDAL, G.J., and HUANG, E.T. (1988). On estimating census undercount in small areas. *Journal of Official Statistics*, 4, 95-112.

- Develops simulation populations based on 1980 census and coverage evaluation results, evaluates regression-based synthetic undercount estimation methods, and shows superiority of synthetic approaches to raw census counts.

JABINE, T.B., and BERSHAD, M.A. (1968). Some comments on the Chandrasekar and Deming technique for the measurement of population change. Paper presented at CENTO Symposium on Demographic Statistics, Karachi, Pakistan.

- Shows that positive correlation bias produces a downward bias in estimate of total population size.

JARO, M. (1989). Advances in record-linkage methodology as applied to matching the 1985 Test Census of Tampa, Florida. *Journal of the American Statistical Association*, 84, 414-420.

- Describes census methodology for matching census and post-enumeration survey records, with the results from their application to 1985 test census.

JELINSKI, Z., and MORANDA, P.B. (1972). Software reliability research. In *Statistical Computer Performance Evaluation*, (Ed. W. Freiberger). New York: Academic Press, 465-484.

- Proposes a model with exponentially distributed failures to estimate total number of program faults based on times of occurrence of failures in fixed time period.

JEWELL, W.S. (1985). Bayesian estimation of undetected errors. In *Bayesian Statistics 2*, (Eds. J.M. Bernardo, *et al.*). New York: Elsevier, 663-671.

JOLLY, G.M. (1965). Explicit estimates from capture-recapture data with both death and immigration - stochastic models. *Biometrika*, 52, 225-247.

- Estimation from multiple-recapture data for open populations.

KADANE, J.B., MEYER, M.M., and TUKEY, J.W. (1992). Correlation bias in the presence of stratum heterogeneity. Submitted for publication.

- Demonstrates the impact of correlation bias resulting from collapsing over heterogeneous strata with different catchability probabilities in each strata, subject to a monotonicity constraint.

KRÓTKI, K.J. (Ed.) (1978). *Developments in Dual System Estimation of Population Size and Growth*. Edmonton: University of Alberta Press.

- Reviews the use of dual system estimation for vital records in various countries. Includes technical details on the use of complex samples and elaborations on basic techniques.

LASKA, E.M., MEISNER, M., and SIEGEL, C. (1988). Estimating the size of a population from a single sample. *Biometrics*, 44, 461-472. Correction, (1989), 45, 1347.

- Estimates population size from the last of k lists.

LEWIS, C.E., and HASSANEIN, K.M. (1969). The relative effectiveness of different approaches to the surveillance of infection among hospitalized patients. *Medical Care*, 8, 379-384.

- Applies dual system estimation to surveillance of infectious diseases.

LINCOLN, F.C. (1930). Calculating waterfowl abundance on the basis of banding returns. *Circular of the U.S. Department of Agriculture*, 118, 1-4.

- Applies capture-recapture method to estimating size of waterfowl populations.

MANTEL, N. (1951). Evaluation of a class of diagnostic tests. *Biometrics*, 7, 240-246.

- Shows how heterogeneity induces correlation bias (event correlation) in the estimation of disease prevalence.

MARKS, E.S., SELTZER, W., and KRÓTKI, K.J. (1974). *Population Growth Estimation: A Handbook of Vital Statistics Measurement*. New York: Population Council.

- Comprehensive review of dual-systems estimation, assumptions, background, design, and problems. Contains claim that the basic method has been used for more than three centuries for estimating size of animal populations.

MAXIM, L.D., HARRINGTON, L., and KENNEDY, M. (1981). A capture-recapture approach for estimation of detection probabilities in aerial surveys. *Photogrammetric Engineering and Remote Sensing*, 47, 779-788.

MULRY, M. H., and SPENCER, B.D. (1988). Total error in the dual system estimator: the 1986 census of Central Los Angeles County. *Survey Methodology*, 14, 241-263.

- Develops a total error model for dual systems approach applied to Los Angeles Test of Adjustment Related Operations.

MULRY, M. H., and SPENCER, B.D. (1991). Total error in PES estimates of population (with discussion). *Journal of the American Statistical Association*, 86, 839-863.

- Extends earlier Mulry-Spencer development of total error model for dual systems approach and applies it to 1988 dress rehearsal census in St. Louis and east-central Missouri.

NICHOLS, J.D., and POLLOCK, K.H. (1983). Estimating taxonomic diversity, extinction rates, and speciation rates from fossil data using capture-recapture models. *Paleobiology*, 9, 150-163.

OTIS, D.L. BURNHAM, K.P, WHITE, G.C., and ANDERSON, D.R. (1978). Statistical inference from capture data on closed animal populations. *Wildlife Monograph*, 62, Washington, DC: Wildlife Society.

- Reviews capture-recapture and related methods for wildlife populations.

PERKINS, W.M., and JONES, C.D. (1965). Matching for census coverage checks. Paper presented at the Meetings of the American Statistical Association, Philadelphia.

PETERSON, C.G.J. (1896). The yearly immigration of young plaice into the Limfjord from the German Sea. Report of the Danish Biological Station to the Ministry of Fisheries, 6, 1-48.

- Classic development of method of capture-recapture and its application to the estimation of the size of fish populations.

POLLACK, E.S. (1965). Use of census matching for study of psychiatric admission rates. *Proceedings of the Social Statistics Section, American Statistical Association*, 107-115.

RAJ, D. (1977). On estimating the number of vital events in demographic surveys. *Journal of the American Statistical Association*, 72, 377-381.

- Develops a formula for bias in dual system estimator under a general model of response errors and explores use of double sampling to correct bias.

ROSSMO, D.K., and ROUTLEDGE, R. (1990). Estimating the size of criminal populations. *Journal of Quantitative Criminology*, 6, 293-314.

RUBIN, D.B. , SCHAFER, J.L., and SCHENKER, N. (1988). Imputation strategies for missing values in post-enumeration surveys. *Survey Methodology*, 14, 209-221.

- Presents a methodology matching for undercount estimation which utilizes an imputation approach rooted in loglinear models in the presence of missing data.

SANATHANAN, L.P. (1972a). Estimating the size of a multinomial population. *Annals of Mathematical Statistics*, 43, 142-152.

- Demonstrates asymptotic equivalence of conditional and unconditional estimators for the population size.

SANATHANAN, L.P. (1972b). Models and estimation methods in visual scanning experiments. *Technometrics*, 14, 813-829.

- Develops latent model to estimate the number of particles in scanning records which allows for differential detectability and induces dependencies amongst detectors.

SANATHANAN, L.P. (1973). A comparison of some models in visual scanning experiments. *Technometrics*, 15, 67-78.

- Applies traditional capture recapture model and latent models to data from actual visual scanning experiments.

SANDLAND, R.L., and CORMACK, R.M. (1984). Statistical inference for Poisson and multinomial models for capture recapture experiments. *Biometrika*, 71, 27-33.

- Shows relationship between the asymptotic variances of the population size under general capture-recapture model for the two alternate sampling schemes.

SCHENKER, N. (1988). Handling missing data in coverage estimation with application to the 1986 Test of Adjustment Related Operations. *Survey Methodology*, 14, 87-98.

- Examines effect of missing data on dual system estimate applied to test census data.

SCHIRM, A.L., and PRESTON, S.H. (1987). Census undercount adjustment and the quality of geographic population distributions (with discussion). *Journal of the American Statistical Association*, 82, 965-990.

- Applies synthetic estimation approaches to 1980 census data to evaluate the impact of undercount estimation.

SCHNABEL, Z.E. (1938). The estimation of the total fish population of a lake. *American Mathematical Monthly*, 45, 348-352.

- Extends the basic capture-recapture approach to multiple recaptures, with information at each recapture on whether individuals were captured previously.

SCOTT, C. (1974). The dual record (PGE) system for vital rate measurement, some suggestions for further development. In *International Population Conference, Liege*, 1973, (Volume 2). Liege: International Union for the Scientific Study of Population.

SEBER, G.A.F. (1965). A note on the multiple-recapture census. *Biometrika*, 52, 249-259.

- Estimation from multiple-recapture data for open populations with time-specific parameters.

SEBER, G.A.F. (1973). *The estimation of Animal Abundance and Related Parameters*. New York: Hafner. Second edition (1982). New York: Macmillan.

- Contains an up-to-date review of capture-recapture techniques and their extensions for animal populations, with emphasis on applications.

SEBER, G.A.F. (1982). Capture-recapture methods. In *Encyclopedia of Statistical Sciences*, (Volume 1), (Eds. S. Kotz and N.L. Johnson). New York: Wiley, 367-374.

- Reviews capture-recapture approach for both closed and open populations and provides guide to wildlife and fisheries applications.

SHAPIRO, S. (1949). Estimating birth registration completeness. *Journal of the American Statistical Association*, 45, 261-264.

- Describes use of 1940 U.S. census data to check on completeness of birth registration using Chandrasekar-Deming estimator.

SHAPIRO, S. (1954). Recent testing of birth registration completeness in the United States. *Population Studies*, 8, 3-21.

- Describes use of U.S. census data from 1940 and 1950 to check on completeness of birth registration using Chandrasekar-Deming estimator.

SIRKEN, M. G. (1978). Dual systems estimators based on multiplicity surveys (with discussion). Chapter 4 in *Developments in Dual System Estimation of Population Size and Growth*, (Ed. K. J. Krótki). Edmonton: University of Alberta Press, 81-91.

- Adapts author's approach of multiplicity surveys for rare events to dual systems problem.

SMITH, P.J. (1988). Bayesian methods for capture-recapture surveys. *Biometrics*, 44, 1177-1189.

- Uses Poisson approximation and Gamma prior for a Bayesian approach to estimation under independence in multiple recapture model.

SMITH, P. J. (1991). Bayesian analyses for multiple capture-recapture model. *Biometrika*, 78, 399-407.

- Develops exact Bayesian posterior distribution for multiple recapture census under independence of recaptures.

SRINIVASAN, S.K., and MUTHIAH, S.A. (1968). Problems of matching births identified from two independent sources. *Journal of Family Welfare*, 14, 13-22.

TRACY, W.R. (1941). Fertility of the population of Canada. Reprinted from *Seventh Census of Canada*, 1931, (Vol. 2), Census Monograph no. 3. Ottawa: Cloutier.

- An early application of dual systems approach to census data.

WINKLER, W.E. (1989). Methods for adjusting for lack of independence in an application of the Felligi-Sunter model of record linkage. *Survey Methodology*, 15, 101-117.

- Examines methods of adjusting linkage rules for matching dual-system records when independence cannot be assumed.

WITTES, J.T. (1974). Applications of a multinomial capture-recapture model to epidemiological data. *Journal of the American Statistical Association*, 69, 93-97.

- Applies multiple systems and independence to estimate the size of a population of children with a congenital anomaly and other problems.

WITTES, J.T., COLTON, T., and SIDEL, V.W. (1974). Capture-recapture methods for assessing the completeness of case ascertainment when using multiple information sources. *Journal of Chronic Diseases*, 27, 25-36.

- Applies multiple systems and independence to estimate the size of a population of children with a congenital anomaly.

WITTES, J.T., and SIDEL, V.W. (1968). A generalization of the simple capture-recapture model with applications to epidemiological research. *Journal of Chronic Diseases*, 21, 287-301.

- Uses capture-recapture approach to estimate number of hospital patients using methicillin.

WOLTER, K. M. (1986). Some coverage error models for census data. *Journal of the American Statistical Association*, 81, 338-346.

- Describes basic version of dual systems approach as used for the 1980 census, including the elimination of erroneous enumerations.

WOLTER, K. M. (1990). Capture-recapture estimation in the presence of a known sex ratio. *Biometrics*, 46, 157-162.

- Uses sex ratio to get a modified capture-recapture estimator for data with stratification by sex, assuming either a common odds ratio, or independence in one stratum. Applies approach to animal data and describes application to census data.

WOLTER, K.M. (1991). Policy Forum: Accounting for America's uncounted and miscounted. *Science*, 253, 12-15.

- Describes 1990 census adjustment procedures and why they are statistically defensible.

WOLTER, K. M., and CAUSEY, B.D. (1991). Evaluation of procedures for improving population estimates for small areas. *Journal of the American Statistical Association*, 86, 278-284.

- Examines through simulations the improvements of synthetic adjustment over the census counts for small areas.

ZALAVSKY, A.M., and WOLFGANG, G.S. (1990). Triple system modelling of census, post-enumeration survey, and administrative list data. *Proceedings of the Section on Survey Research Methods, American Statistical Association*, 668-673.

- Applies various loglinear and related models of dependence to analyze triple system data from census dress rehearsal in St. Louis.