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Technical Article 1

RANDOMIZATION TESTS

by

H. Charles Romesburg[1]

Within 20 years the use of t- and chi-square statistics to test statistical hypotheses may be infrequent. Randomization tests will succeed many of the parametric and nonparametric tests comprising today's textbooks.

Randomization tests, a class of nonparametric tests, are intuitively plausible and simple to understand. They are performed by taking the given sample of data and "reshuffling" it into all possible alternative forms. The P-level is the fraction of all possible reshufflings that are, under the null hypothesis being tested, at least as deviant as the observed sample.

Conceived by R. A. Fisher nearly a half-century ago (Fisher, 1941), randomization tests have held promise as a superior, if not ultimate, kind of statistical test, but at the same time have remained impractical curiosities. As Bradley (1968, pp. 68-86), Conover (1971, pp. 357-364), and Feinstein (1977, pp. 287-304) observe, randomization tests are superior to their parametric and nonparametric counterparts on almost all points:

(1) Randomization tests are nearly free of assumptions. Nothing more than a random sample of data is required. Assumptions that are sometimes hard to meet in practice are not binding: such as the assumption of equality of population variances for a t-test of the difference between the means of two populations, the assumption of normality, or the condition that expected cell frequencies must be greater than five for chi-square tests to be valid. Thus, assumptions that often must be based on faith and hope are swept out of mind. The principle is that the less assumptions a statistical test is founded upon, the smaller will be the chance that the test will turn out to be accidentally invalid. It is true that other nonparametric tests also have this property, the Mann-Whitney or Wilcoxon tests, but randomization tests have other desirable features setting them further apart.

(2) Randomization tests require no tabulated values of the test statistic. Unlike conventional parametric and nonparametric tests, the P-level is calculated directly. As a result, there is no problem with finding the proper number of degrees of freedom. With randomization tests, the concept of degrees of freedom is irrelevant.

(3) As Bradley (1978, p. 83) points out, randomization tests have the good mathematical and statistical properties of the corresponding classical parametric tests when the corresponding normal distribution theory assumptions happen to be true. For example, unlike other nonparametric tests, randomization tests are virtually as powerful (large power = small Type II error) as their parametric counterparts. Hoeffding (1952) has shown that in many situations randomization tests have an asymptotic relative efficiency of 1.0. And Kempthorne and Doerfler (1969) have shown that, for small sample size, which frequently is the case in practice, a randomization test, judged on a variety of criteria, is superior to the Wilcoxon and sign tests. Thus, in using a randomization test, one gets the desirable properties such as "most powerful," consistent, unbiased, etc. that characterize the classical tests based upon normal distribution

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theory while not being forced to make any assumptions in order to obtain these benefits.

Overall, randomization tests have many advantages, but they also require many calculations. The number of possible reshufflings of the sample data increases exponentially with sample size, and only trivial problems can be solved by hand. That is why randomization tests get short shrift in the statistical textbooks. Bradley (1968), for instance, described them as "stunningly efficient" but "dismally impractical." But computer technology is in the process of making randomization tests practical. Both developments in hardware, giving faster computers, and the availability of canned computer programs for randomization tests, have increased the feasibility of putting these tests into practice.

The purpose of this note is to discuss and give examples of the use of several computer programs for randomization tests. At present, I am aware of FORTRAN programs for three tests: (1) R rows by C columns contingency table independence tests; (2) goodness-of-fit tests fitted to expected distributions; and (3) tests of the differences in the means of two populations. Most statistical textbooks suggest that the chi-square statistic be used for the first two tests and that the t-statistic be used on the third.

R by C Contingency Table

The chi-square test of independence for this 3 by 3 table of count data gives a probability

4	2	1
0	2	3
1	3	5

level (P-level) of P = 0.126 while the true value computed by the randomization test is P = 0.204. Why is the chi-square test incorrect? The low expected cell frequencies make it so (e.g., the expected cell count for the cell in the third row and first column is 1.7). In cases where all assumptions necessary for the chi-square test to be valid are met, the two tests will give virtually identical results.

The concept of "reshuffling the data" is easily understood in terms of this example. The row and column marginals are regarded as fixed once the given sample of data is obtained. All other tables consistent with these marginals are obtained by the computer program; each occurs with a given probability, under the null hypothesis of independence, which is calculated. Those tables that are as deviant as the observed table (including the observed table) have probabilities that are summed up to give the P-level; the term "deviant" is mathematically defined by an index in a variety of ways depending on what hypothesis is being tested.

Goodness-of-Fit

Suppose we test the hypothesis that the following data (the observed cell counts) came from a geometric distribution (defined by the expected cell counts):

OBS:	1.0	4.0	2.0	1.0	3.0	0.0	1.0	1.0
EXP:	5.2	3.1	1.9	1.1	0.7	0.4	0.2	0.4

A chi-square test with 7 degrees of freedom gives P = 0.028, and we'd reject the null hypothesis at $\alpha = 0.05$. However, the randomization test gives P = 0.052, and we'd fail to reject. The chi-square test is invalid because of the small expected values. Most researchers would doubtless be aware of this and counter by using a nonparametric test such as the Kolmogorov-Smirnov (KS) test, which is valid with small sample sizes. However, the randomization test is preferred because (1) the KS test is deficient in statistical power and (2) is invalid when, as is the usual case, the expected distribution is estimated from the observed count data (Lilliefors 1967).

Differences Between Two Means

Consider the following difference test between two population means: Suppose we have a random sample of size $n_1 = 4$ from the first population which contains these values: 2.4, 2.5, 2.3, 2.2; a random sample from the second population of size $n_2 = 7$ contains these values: 3.5, 2.1, 3.7, 2.4, 3.6, 3.4, 3.5. The hypothesis of no difference would be rejected at the $\alpha = 0.05$ level using the t-test (P = 0.035) while it would not be rejected using the randomization test (P = 0.079). The populations from which these samples were drawn were contrived to be non-normal with unequal variances. Hence, the t-tests are invalid.

These three randomization tests cost less than one dollar to perform on a computer, hardly dismally impractical. The FORTRAN computer programs used were located in the statistical literature, and all were easily converted to the Burroughs B6800 Computer at Utah State University. The two versions of the R by C contingency table test (Agresti and Wackerly 1977; Agresti et al. 1979), a goodness-of-fit program (Romesburg 1981), and a difference-in-means program (Green 1977) are available from the authors. A tutorial (Feinstein 1977) details the theory of randomization tests outlined here.

To perform a randomization test, a researcher must have (1) a computer program for the desired test and (2) access to a computer. Given these conditions, Green (1977) believes that the features of randomization tests make them preferable to any parametric tests when the assumptions they are founded on may not hold, and preferable in virtually all situations to other nonparametric tests. These conditions however, are not always met in practice. The three cited computer programs perform three widely used statistical

tests, yet in many instances a researcher will need to perform a randomization test for which no computer program exists. For example, multi-sample tests for unequal locations of identical populations can be performed with a randomization test (Bradley 1968, pp. 80-83). But to my knowledge, no computer program for this is yet available. Computer programs for randomization tests are too complex to expect researchers to write their own. Thus, unavailability of a program is a valid reason for not using a randomization test.

In cases where the validity of parametric tests is suspect, it makes sense to go to the trouble of using a randomization test when a computer program is available. If a computer is not available, it makes sense to pay the modest costs to gain access. To do otherwise risks an invalid statistical analysis on a set of data that may have been costly to assemble.

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1980 RPA ASSESSMENT DATA FILES AVAILABLE FOR DISTRIBUTION

As the nationwide efforts drew to a close in the compilation of data to support the 1980 RPA Assessment of the Forest and Range Land Situation in the United States, the RPA Coordination Group discussed the maintenance of the automated data bases. Responsibility for this task was given to the Rocky Mountain Forest and Range Experiment Station in Fort Collins, Colorado. The RM Station established the Data Base Maintenance Group under the Resource Evaluation Techniques Program early in 1980.

Presently, the DBMG is comprised of three subject-area specialists and a computer programmer. Each of the elements of the Assessment which had automated data bases are represented: Timber (Gary Dixon), Range (Sharon Wooten) and Wildlife and Fish (Chuck Rushing). Both the data files and the tabular summaries used by the Assessment analysts are available for distribution by contacting the appropriate subject area specialist at:

Rocky Mountain Forest and
Range Experiment Station
240 West Prospect Street
Fort Collins, CO 80526
Phone: (303) 221-4390, ext. 489
or FTS 323-1489.

A brief description of each subject-area data base follows:

Timber

The timber data base contains state summary data for forest area, timber volume, and timber products output. The data are available for the year in which the state inventory was conducted and 1977, the common base year of data aggregation for the national assessment. Certain portions of the area and volume data include historic data for 1952, 1962, and 1970. The data base also contains national summary tables which were used to produce Appendix 3, "Forest Statistics of the U.S., 1977," in "An Analysis of the Timber Situation in the United States, 1952-2030" by the USDA Forest Service. For further information, or data requests, please contact Gary Dixon as noted above.

Range

The range base consists of range, timber, and wildlife data organized by factors such as vegetation type (potential natural communities), land ownership, productivity class, condition class, state, RPA region, and Forest Service

region. Data are available that indicate the various resource outputs and effects that could be expected from management strategies and their associated costs. Management scenarios, developed by scientists who participated in workshops, describe the levels of management thought to be applicable now and in the foreseeable future for each community. A scenario also identifies endangered and threatened species that inhabit the area, and other factors for consideration in managing a particular community. Data are available by contacting Sharon Wooten at the above address.

Wildlife and Fish

The wildlife and fish data base contains information on ecosystems, habitat relationships, management potential, and relative importance of timber size class, range condition class, or aquatic ecosystem for wildlife and fish species. The data are available for all vertebrate species inhabiting land and associated waters of the Continental United States, Alaska, Hawaii, and the Caribbean and Pacific Territories. Limited population and consumptive use projections are available on species of special interest such as game or commercially important vertebrates. Data can be sorted on a national, regional, or state level. For further information, contact Chuck Rushing as indicated above.

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INPLACE RESOURCE INVENTORIES: PRINCIPLES AND PRACTICES

Today's land managers need maps showing the location, amount, and condition of their renewable natural resources. The inventory or resource specialist needs to be able to attach sampled attributes to mapped areas, and be able to estimate the reliability of the displayed data. The computer specialist needs to be able to store, manipulate, and display the map and inventory information. These topics will comprise the theme of a national workshop on Inplace Resource Inventories to be held in Orono, Maine, August 9-14, 1981.

The workshop is being sponsored by The American Society of Photogrammetry, The Renewable Natural Resources Foundation, The Society of American Foresters, The Society for Range Management, and The Wildlife Society. Cooperating agencies include the Forest Industries of Maine, the USDA Forest Service and Soil Conservation Service, the USDI Bureau of Land Management, Fish and Wildlife Service, and Geological Survey, and the University of Maine.

The objective of this workshop and subsequent proceedings is to provide both beginning and practicing inventory specialists with alternative methods of producing reliable inventories and maps of the resources. The workshop will include discussions on management, information needs, inventory planning, what needs to be mapped, what needs to be sampled, how sampling is done, sampling techniques and options, creating a computer data base, maintaining the base (including coping with changes in information, policy, techniques, and equipment), and applications in using graphic and data base systems.

There will be two concurrent courses within the workshop. Concurrent Course I will concentrate on the Principles of Inplace Resource Inventories, and will be focused toward the beginning inventory specialist or manager who wants a good introduction to the subject matter. Course II will deal with current practices and state-of-the-art papers. It's main thrust will be toward the experienced designer, researcher, and educator. Participants are required to register for one course or the other, but there will be an opportunity to sit in on the other sessions. Concurrent workshop tours to Sewall Company and Great Northern Paper Company will also be available.

Registration will be limited on a first come-first served basis. The fee will be $60 due July 1, 1981. Student housing will be available at approximately $30 per day. This includes room, board, and transportation to and from the airport at Bangor. Also included in this fee is a social hour and dinner on August 9 and a lobster picnic on August 12. Tickets to these two events will be available for purchase at the start of the workshop for those wanting to stay off campus.

For information on registration, accommodations, and guest programs and tours, contact:

Mr. John Benoit
Conferences and Institutes Div.
University of Maine
128 College Ave.
Orono, ME 94473
Phone (207) 581-2626

A call for commercial exhibits, poster displays, and contributed papers is open until March 1, 1981. Space is limited, and each will be selected based upon appropriateness to the theme of the workshop.

For commercial exhibits contact:

Roger E. Greene
Seven Islands Land Company
Ashland, ME 04732
Phone (207) 435-6039

For poster session display contact:

Meredith J. Morris
USDA Forest Service, RMF&RES
240 West Prospect St.
Fort Collins, CO 80526
Phone (303) 221-4390, ext. 256; FTS 323-1256

For contributed papers, send title and abstract to:

H. Gyde Lund
USDA Forest Service, RMF&RES
240 West Prospect St.
Fort Collins, CO 80526
Phone (303) 221-4390, ext. 202; FTS 323-1202

International participation is encouraged.

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HABITAT EVALUATION PROCEDURES

In 1976, the U.S. Fish and Wildlife Service (FWS) published a methodology for use in evaluating fish and wildlife habitat, entitled the Habitat Evaluation Procedures (HEP). This methodology has been reviewed and updated over the past four years, resulting in the development of several supporting documents. The HEP Manual and supporting documents include:

ESM 101	Habitat as a Basis for Environmental Assessments.
ESM 102	Habitat Evaluation Procedures.
ESM 103	Standards for Development of Habitat Suitability Index Models for use with the Habitat Evaluation Procedures.
ESM 104	Human Use and Economic Evaluation.

These may be ordered from Publications Clerk, Western Energy and Land Use Team, U.S. Fish and Wildlife Service, Creekside One, 2625 Redwing Road, Fort Collins, CO 80526.

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INTERNATIONAL STATISTICAL INSTITUTE

Statistics and Stochastics in Forestry will be the subject of a half-day meeting during the Forty-third Session of the International Statistical Institute (ISI). This session will be held in Buenos Aires between November 30 and December 11, 1981. The program has been organized by ISI and its adjoined associations (Bernouilli Society for Mathematical Statistics and Probability, International Association for Statistical Computing, International Association of Survey Statisticians). Other subjects include: Designs of Experiments, Stochastic Processes in Genetics, Conceptual and Theoretical Framework for Survey Sampling, and Statistical Abilities of Computer Software. Four persons have been invited to present papers at the meeting on Statistics and Stochastics in Forestry:

Fernando Cox of the Undiversidad Austral de Chile will treat a topic connected with survey methods (title not decided).

Peter Diggle of the University of Newcastle upon Tyne, will deal with "Multivariate spatial patterns in cleaning stands."

J. P. Lanly of the Forestry Department, FAO, will treat "Methods used to assess the present status and the probable development of the world's forest resources."

Hans T. Schreuder of the Rocky Mountain Forest and Range Experiment Station is speaker on the subject, "Multiresource sampling strategies in the United States for timber, range, recreation, and wildlife data."

The meeting presents a unique opportunity to have the statistical methods used in forestry debated by experts in statistical theory and experts on applications in other fields.

It is, of course, highly desirable that we get a good attendance of people interested in the application of statistics to forestry and forest science. It appears that the best way to get an invitation to the Buenos Aires meeting is to join the International Association for Survey Statisticians (Secrétariat AISE, c/o INSEE, 18 Blvd. A. Pinard, F-75675 Paris-Cedex 14, France), or one of the other adjoined societies. If you want more information, write to Bertil Matérn (Box 7008, S-75007, Uppsala, Sweden).

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INTERAGENCY WILDLIFE GROUP (IWG) ACTIVITIES

The charter for the IWG was completed, approved by the Resources Evaluation Techniques (RET) Program, and submitted to the Five-Agency Program Coordination Committee for their review and concurrence by the Five-Agency Policy Group.

Members of the IWG participated in a meeting with the Five-Agency Program Coordination Committee and RET Program personnel held in Fort Collins October 14-17. The role of the IWG in the RET Program was defined, and guidelines were developed.

The chairman of the IWG (Jim Whelan) attended the annual meeting of the International Association of Fish and Wildlife Agencies (IAFWA) and presented a status report on the IWG organization and activities to the Executive Committee of the Association. The IWG is working closely with the IAFWA, RET Staff, Five-Way agencies, and the National Governors' Council Representative to the Five-Agency Agreement to draft a document which describes the importance of state/federal cooperative efforts in meeting the long-term wildlife/fish resource assessment objectives of the IWG. This document will emphasize how various products of the RET Program can provide useful information for meeting state agency planning needs for wildlife and fish. The document will be sent through the IAFWA to all directors of state wildlife and fish agencies.

Henry Short, FWS representative to the IWG, and Jim Whelan are serving on a steering committee comprised of representatives from federal and

Colorado natural resource agencies, which was organized to assist the Colorado Division of Wildlife in an information needs assessment for determining the applicability of the Fish and Wildlife Service's "Procedures for Describing Fish and Wildlife," and other wildlife/fish data bases to meet Colorado's needs for wildlife and fish data.

Cliff Hawkes (FS), Dave Chalk (SCS), and Jim Whelan (FWS) attended a two-week (80 hour) short course on simulation modeling presented by the Range Science Department of Colorado State University from October 27 - November 7.

Patrick Festa, Fisheries Biologist with the New York State Department of Environmental Conservation, was selected as the IPA Fishery Biologist for the IWG. Pat will be assigned to the Classification Project of the RET Program, and is scheduled to begin work on March 1, 1980.

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MEETINGS, WORKSHOPS, AND SYMPOSIA

February 8-13, 1981. Society for Range Management Annual Meeting. (Tulsa Oklahoma). Contact: Executive Secretary, SRM, 2760 W. 5th Ave., Denver, CO 80204.

February 9-13, 1981. Aerial Photography/Aerial Photo Interpretation. An introductory or refresher course for land managers. $175. Contact: Dr. Joseph J. Ulliman, College of Forestry, Wildlife and Range Sciences, Univ. of Idaho, Moscow, ID 83843. Phone (208) 885-7016.

February 22-27, 1981. ASP-ASCM National Convention. (Washington, D. C.) Contact Les Perry, Publicity Chairman, 2521 Forest Glen Road, Silver Spring, MD 20910. Phone (301) 443-8985.

March 2-6, 1981. Short Course on the Application and Processing of Landsat Data. No registration fee. Continuing education units (CEU) are available if requested. Co-sponsored by Murray State University and the National Aeronautics and Space Administration. Contact: Dr. Neil V. Weber, Director, Mid-America Remote Sensing Center, Murray State University, Murray, Kentucky 42071. Phone (502) 762-2148.

March 17-20, 1981. The Application of Remote Sensing to Wildlife Habitat Inventory. Contact: P. J. Gutierrez (phone (707) 826-3320) or L. Fox (phone (707) 826-4873). School of Natural Resources, Humboldt State Univ., Arcata, CA 95521.

April 6-11, 1981. Perspectives in Landscape Ecology: Contributions to Research, Planning and Management of Our Environment. (Eindhoven, The Netherlands). Contact: Ms. W. J. M. van Giersbergen, Congress Bureau of the Information Dept. TNO, 148, Juliana van Stolberglaan, 2595 CL The Hague - The Netherlands.

April 20-23, 1981. Energy and Ecological Modelling - An International Symposium. Contact: Dr. William J. Mitsch or Dr. Robert W. Bosserman, Systems Science Institute, Univ. of Louisville, Louisville, KY 40292. Phone (502) 588-6482.

April 21-23, 1981. Eighth Biennial Workshop on Color Aerial Photography in the Plant Sciences and Related Fields. (Shenandoah National Park, Virginia). Contact: Dr. Roy A. Mead, Program Chairman, VIP and State Univ., Blacksburg, VA 24061. Phone (703) 961-5481.

May 4-15, 1981. Forest Industries Management Development Program. $1,900. Includes all fees, meals, and lodging. Contact: Management Development Programs, 708 Stokely Management Center, Univ. of Tennessee, Knoxville, TN 37916.

May 11-15, 1981. Fifteenth International Symposium on Remote Sensing of Environment. Contact: Dr. Jerald J. Cook, ERIM, P. O. Box 8618, Ann Arbor, MI 48107. Phone (313) 994-1200.

June 22-26, 1981. Dynamics and Management of Mediterranean-type Ecosystems: An International Symposium. (San Diego, California). Contact: Chairman, Dynamics and Management of Mediterranean-type Ecosystems: An International Symposium, Pacific Southwest Forest and Range Exp. Stn., USDA Forest Service, 4955 Canyon Crest Drive, Riverside, CA 92507.

June 26-October 2, 1981. Ninth Forest Research Course of the Commonwealth Forestry Institute. Contact: H. L. Wright, Dept. of Forest Science, Commonwealth Forestry Institute, Univ. of Oxford, Oxford, OX1 3RB, England.

★ U.S. GOVERNMENT PRINTING OFFICE: 1980—778-032/156

July 7-10, 1981. Use of Programable Calculators in Forestry.

July 13-17, 1981. Regression Methods in Resource Analysis.

July 20-24, 1981. Multilevel Sampling. For information on all three of the above short courses, contact Dr. Warren E. Frayer, College of Forestry and Natural Resources, Colorado State University, Fort Collins, CO 80523. Phone (303) 491-6637.

August 9-14, 1981. "INPLACE Resource Inventories --A National Workshop." (Orono, Maine). Sponsored by The Renewable Natural Resources Foundation, Society of American Foresters, Society for Range Management, American Society of Photogrammetry, Wildlife Society, and in cooperation with the Forest Industries of Maine, University of Maine, the USDA Forest Service, Soil Conservation Service, USDI Bureau of Land Management, Fish and Wildlife Service, and the Geological Survey. Contact: John Benoit, Orono, ME 94473. Phone (207) 581-2626.

September 6-17, 1981. Seventeenth IUFRO World Congress. (Kyoto, Japan). Contact: Congress Secretariat, XVII IUFRO World Congress, P. O. Box 16, Tsukuba Norin, Kenkyudanchi-Nai, Ibaraki, Japan 305.

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WANTED--Materials for the Newsletter--feature articles, news items, current literature, and meeting notices. All articles received are to be grammatically and technically correct. Send your material to Resources Evaluation Newsletter, Rocky Mountain Forest and Range Exp. Stn., 240 West Prospect Street, Ft. Collins, CO 80526. Phone: (303) 221-4390, ext. 202 or FTS 323-1202.

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