Statistical and Theoretical Research

Research in fiscal year 1982 has led to the development of improved statistical methods for quantifying and assessing environmental changes produced by energy developments. In light of these advancements, the descriptive studies of years past have become obsolete.

At PNL, scientists are studying the fate of contaminants in ecosystems. Using controlled studies, census techniques, and models of population dynamics, we have developed methods capable of detecting changes in the abundance of animals as a result of either contaminant exposure or landscape manipulations (e.g., construction activities, cooling ponds, buried wastes of non-nuclear or nuclear origin).

Significant accomplishments include the creation of field designs to detect population impacts, new census procedures for small mammals, and methods for designing studies to determine where and how much of a contaminant is extant over certain landscapes.

A book describing these statistical methods is currently being written and will apply to a variety of environmental contaminants, including radionuclides. PNL scientists also have devised an analytical method for predicting the success of field experiments on wild populations. Two highlights of current research are the discoveries that population of free-roaming horse herds can double in four years and that grizzly bear populations may be substantially smaller than once thought. As stray horses become a public nuisance at DOE and other large Federal sites, it is important to determine their numbers. Similar statistical theory can be readily applied to other situations where wild animals are a problem of concern to other governmental agencies. Another book, on statistical aspects of radionuclide studies, is written specifically for researchers in radioecology; the book will be of use to scientists in other areas of research as well.

EXAMINING THE FATE OF CONTAMINANTS FROM ENERGY DEVELOPMENTS

Efficient field sampling designs, backed by statistical analyses, enable scientists to assess public health and safety impacts from exposure to radionuclides more quantitatively. The focus of this effort is on data handling and development; that is, describing the pattern of distribution of radionuclides in the environment, estimating concentrations within ecosystems, and designing sampling schemes to assess the need for cleanup activities. Such analyses tell us whether contaminant levels comply with environmental guidelines and regulations.

Communications between statisticians and scientists doing radionuclide studies are being improved by publishing a variety of articles of common interest and by distributing TRANS-STAT, a publically available newsletter, to Department of Energy contractors. Publication of the newsletter fulfills PNL's objective of making information available to principal users. The upcoming publication of a book based, in part, on past issues of TRAN-STAT will make these methods widely available to the general scientific community. Several commercial publishers have offered to publish the 17-chapter manuscript, which includes information on how to estimate transfer coefficients using ratios, design field surveys and studies, assess the uncertainty of dose-transport model predictions, and estimate the spatial distribution and inventory of contaminants.

Three new topics were developed and published in TRAN-STAT during fiscal year 1982. Issues 17 and 18 of the newsletter completed a series on extreme-value theory in radionuclide studies; Issue 19 described statistical design aspects of finding "hot spots" of contamination in the environment; and Issue 20, contributed by the Los Alamos National Laboratory, examined ways of statistically estimating parameters in nonlinear transport models. Issues for the coming year will include articles on using ratios to estimate transfer coefficients, doing probability plotting, designing field studies, and assessing uncertainty in dose-transport models.

In 1982, we again assisted the Nevada Applied Ecology Group with statistical design and analysis aspects of radionuclide studies on the Nevada Test Site. This work involves the continued development of Kriging methods for estimating the spatial distribution of radionuclides. In other related work, we provided the NRC with statistical designs for its field studies on stabilizing tailings

piles. We also analyzed both uranium bioassay and in vivo measurements from participating NRC licensed uranium mills (NRC funded). In addition, the PNL staff helped prepare a guide book on decommissioning and decontaminating waste sites for DOE. Of particular interest was DOE's decision to hold a workshop on the ocean disposal of low-level radioactive waste in which PNL staff participated (Division of Remedial Action).

CENSUSING WILD AND STRAY POPULATIONS OF LARGE ANIMALS

The construction and production operations of energy facilities potentially affect the dynamic responses of animals in their natural habitat, particularly at sites where the land holdings are extensive. Because populations of either wild or stray animals cannot be studied in the laboratory, accurate field techniques are needed to determine how these populations respond to environmental pressures. To date, several new census methods and population dynamics models have been developed by PNL scientists that allow the accurate census of large animals such as horses. The methods are widely applicable to other animals such as the grizzly bear, the bowhead whale, and the manatee. Studies of the latter species are important to other agencies because the animals are included on the endangered species list or are actively considered for inclusion on that list. Our ability to cooperate with other concerned agencies has permitted the use of a wider data base needed for sound development of the statistical theory for wildlife of concern to DOE.

The National Marine Fisheries Service, the National Park Service, and the Fish and Wildlife Service have primary responsibility for managing these populations of large animals. Also involved are the International Whaling Commission, the U.S. Marine Mammal Commission, the National Academy of Sciences, and the Bureau of Land Management.

In a study of horse herds last year, PNL discovered that the size of a free-roaming herd may double in only four years. Direct aerial counts at a site in Oregon show that the herd's population increase rate approached 20% per year, a rate that can be achieved

Horses Can Be a Public Nuisance at Large Federal Sites. In Oregon, aerial counts taken this year indicate that wild horse herds have higher survival and reproduction rates than domestic horses (*see text*).

only if survival and reproduction rates are higher than those of domestic horses. Adult survival was found to be high.

Nine papers covering research on this project were published in fiscal year 1982. The investigators also contributed to the efforts of two national committees and held continuing faculty appointments at two universities and at the Joint Center for Graduate Study in Richland, Washington. Through these studies and our other methodology research, we are developing management approaches that seek to balance the real risks to an endangered species against energy development needs.

The PNL staff has also created and published a census method for use in the controlled removal of animals and continued to do research on population regulation and dynamics. The latter work included publishing an assessment of the unusual rate of growth in feral horses. Computer models to determine the population dynamics of a number of species were also implemented. Finally, we are working on a book that summarizes this area of statistical research.

DESIGNING STUDIES TO DETECT EFFECTS ON MOBILE SPECIES

Small, wild animals that are naturally present on the site of industrial facilities often cause a variety of safety and other problems. Their reclusive nature makes an accurate population count nearly impossible, so investigators must usually base their population studies on mere estimates of animal abundance. Unfortunately, population estimates tend to be imprecise. This reliance on estimation rather than on direct measurement distinguishes these particular wildlife studies from other ecological sampling programs.

Through computer studies, we have found that the standard statistical approaches (as used in agriculture, sociology, and industrial quality control) are not appropriate for quantifying effects on mobile wildlife species. Statistical tests supposedly performed at a significance level of $\alpha = 0.5$ are actually at the 0.3 or 0.4 level, values which are very little different from chance (i.e., 50/50). Similarly, when a population changes, the standard analyses are less likely to detect that change compared to the special statistical tests recently developed at PNL.

Data transformations have proved to be an important aspect of the development of the new statistical methods. We have found that

Population Abundance Is One Method of Measuring Whether Or Not Particular Animals Are Affected by Pollutants.

the appropriate transformation of abundance data depends on the type of census technique used. When a capture-tag-recapture method is used, a logarithmic transformation of the data is required. However, when a removal census (catch-per-unit-effort) is used, an "inverse" transformation is necessary. Appropriate data transformation can increase the power of statistical tests of treatment effects by as much as 20% with no additional expense to the field study.

Another area of improvement has been to devise new statistical methods (i.e., "treatment effects") when attempting to compare the effects of different treatments on animal populations, as for example testing for effects of pollutants. The traditional reason for censusing wild populations has been to estimate animal numbers in order to manage the resource purposely. This leads to inappropriate methods for comparing treatment effects. By using the "catch" index present in all wildlife census techniques, we have developed statistical tests that are 2 to 20 times more efficient than comparable methods which use the absolute abundance data from

wildlife censuses. Again these improvements do not increase the cost of field studies and, furthermore, sometimes can actually decrease the cost of expensive wildlife studies.

In reviewing the biological and statistical literature, we found no useful guidelines for designing effective field studies to test for changes in populations. The practical consequence of this finding is that many apparently well-conceived field studies are virtually designed to fail. In current work, therefore, we have developed the first analytical calculations for computing the probable success of proposed field experiments. To date, these analytical techniques enable us to make comparisons of only two populations at one time. For more complex scenarios involving multiple populations subject to environmental impacts, Monte Carlo computer techniques were used to assess probable success rate. We are now developing simple hand calculations for these larger field studies.

Specific information about the populations being compared is necessary to design cost-effective studies and may have to be obtained in advance of determining treatment effects. Information, however, is needed in the following areas:

- expected size of populations
- sampling precision
- variability in population numbers across the landscape
- costs of establishing study plots versus costs of trapping.

Field data and cost functions can then be combined to yield optimal field study designs.

Optimization techniques will be an important tool of the future, because they can be used to determine the most useful sampling program and cost-effective approach for a wildlife study. If the optimal design is determined to be economically unfeasible, all alternative approaches will necessarily also be ineffectual, thus suggesting that dollars for environmental studies should be spent elsewhere.

For conducting long-term studies of population dynamics, we have developed an algorithm that can be used to determine the optimal size of a study plot and the appropriate trapping effort to use in censusing a population. This algorithm eliminates much of the guess work in designing a population study and results in the greatest sampling precision for the monitoring dollars available. We are now conducting research to extend this capability to multi-plot population studies.

Multi-plot population studies must balance trapping costs and census precision with the costs of establishing study sites and the natural heterogeneity in animal numbers across the landscape. During the last year, two important findings have brought us closer to optimizing such field studies, which are inherently more complicated. First, we developed and field tested a model for predicting the effect that alternative levels of effort may have on sampling precision. Second, we identified a relationship which allows us to predict plot-to-plot variance knowing mean animal abundance. These relationships will be used to determine the effect that alternative levels of field replication (number of plots) and sampling (trapping effort) will have on the capacity of field studies to detect reasonable changes in animal numbers with both statistical assurance and significance.

ACKNOWLEDGMENTS

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PUBLICATIONS

Skalski, J. R., D. S. Robson and M. A. Simmons. "Comparative Census Procedures Using Single Mark-Recapture Methods." Ecology (in press).

MANUSCRIPTS SUBMITTED FOR PUBLICATION

Skalski, J. R., M. A. Simmons and D. S. Robson. 1982. "The Use of Removal Sampling in Comparative Censuses." Ecology (submitted).

Skalski, J. R., D. S. Robson and C. L. Matsuzaki. 1982. "Competing Probabilistic Models for Catch-Effort Relationships in Wildlife Censuses." Ecological Modeling (submitted).

Skalski, J. R. 1982. "A Variable Effort Census Technique for Estimating Animal Abundance." J. Wildl. Manage. (submitted).

Interagency Research

Environmental and energy assessment, to be effective, requires the cooperation of many governmental agencies and sponsors. The research topics identified in this section are complementary to work discussed in other sections of this report, but do not duplicate our DOE work.

BONNEVILLE POWER ADMINISTRATION

Environmental Information Gathering and Evaluation Related to River Operations (Principal Investigator: D. H. Fickeisen)

Biological Studies of a 1200-kV Prototype Transmission System near Lyons, Oregon (Principal Investigator: L. E. Rogers)

ENVIRONMENTAL PROTECTION AGENCY

Fate and Effects of Toxic Substances on Marine Ecosystem Processes (Principal Investigator: J. W. Anderson)

Ecological Effects of New Coal Conversion Technologies (Principal Investigator: D. H. Fickeisen)

Quantitative Methods for Detecting Environmental Pollution (Principal Investigator: J. M. Thomas)

Radiation Dose-Risk Estimates Associated with the Practice of Deep Sea Disposal of Low-Level Nuclear Waste (Principal Investigator: W. L. Templeton)

Cold-Climate Research and Development Program (Principal Investigator: J. B. States)

Biomonitoring Using Honeybees (Principal Investigator: J. M. Thomas)

Field Evaluation of Hazardous Waste Site Bioassays (Principal Investigator: J. M. Thomas)

Collection of Sediment from Commencement Bay, Washington (Principal Investigator: E. A. Crecelius)

KNOLLS ATOMIC POWER LABORATORY

Benthic Boundary Layer Program (Principal Investigator: J. S. Young)

NATIONAL INSTITUTE OF ENVIRONMENTAL HEALTH SCIENCES

Fate of Heavy Metals and Heavy Metal Complexes in Soils and Plants (Principal Investigator: R. E. Wildung)

NATIONAL OCEANOGRAPHIC AND ATMOSPHERIC ADMINISTRATION

Effect of Oil on the Behavior of Clams and Worms (Principal Investigator: W. H. Pearson)

Organic Pollutants in Waterways Adjacent to Commencement Bay (Principal Investigator: R. G. Riley)

Dosing of Oysters with Stable and Radioactive Cadmium (Principal Investigator: J. T. Hardy)

Significance of Metal-Binding Proteins and Lysosome-Like Vesicles in Mussels in a Metal-Contaminated Environment: An Experimental Field Study (Principal Investigator: G. Roesijadi)

Outer Continental Shelf Environmental Assessment Program (Principal Investigator: W. H. Pearson)

History of Contaminant Accumulation in Puget Sound and Commencement Bay, Washington (Principal Investigator: E. A. Crecelius)

Fate of Pollutants Discharged to Puget Sound: Accumulation in Sediments and Marine Birds (Principal Investigator: R. G. Riley)

NUCLEAR REGULATORY COMMISSION

Environmental Standard Review Plans (Principal Investigator: D. G. Watson)

Quantitative Assessment of Aquatic Impacts of Power Plants (Principal Investigator: D. H. McKenzie)

NUCLEAR REGULATORY COMMISSION (contd)

Biocide By-Products in Aquatic Environments (Principal Investigator: R. M. Bean)

Relevance of Biotic Paths to the Regulation of Nuclear Waste Disposal (Principal Investigator: D. H. McKenzie)

Changes in Bioavailability of Low-Level Radioactive Effluents After Passage Through Soil (Principal Investigator: D. G. Watson)

Statistical Methods for Siting and Managing Low-Level Radioactive Waste Sites (Principal Investigator: T. L. Page)

Safety Implications of Biofouling at Nuclear Power Plants (Principal Investigator: T. L. Page)

Relevance of Biotic Paths to the Regulation of Nuclear Waste Disposal (Principal Investigator: D. H. McKenzie)

OAK RIDGE NATIONAL LABORATORY

Coordination and Planning of Acid Deposition Research for the Interagency Task Force (Principal Investigator: D. H. McKenzie)

U.S. FISH & WILDLIFE SERVICE

Analytical Support for Studies of Effects of Oil Production on Aquatic Organisms (Principal Investigator: R. G. Riley)

U.S. GEOLOGICAL SURVEY

Development of Cost-Effective Biomonitoring Techniques for Federal Oil Shale Lease Tracts (Principal Investigator: J. R. Skalski)