FINAL REPORT

U.S. Department of Energy

ESTIMATION OF POTENTIAL POPULATION LEVEL EFFECTS OF CONTAMINANTS ON WILDLIFE

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EXECUTIVE SUMMARY

The purpose of the project was to improve the methods used to assess the risks of contaminants to wildlife. Currently, this assessment is based on the assumption that literature-derived toxicity test endpoints (e.g., mortality and reproduction) that are based on individual animals can be used to estimate thresholds for population-level effects. Moreover, species sensitivities to contaminants must be considered when selecting assessment endpoints, yet data on the sensitivities of many birds and mammals are unavailable. Results obtained in this research will be used to more accurately assess risks of contaminants to wildlife populations and thereby avoid unnecessary costs resulting from risk assessments that are too conservative because of data limitations.

Several significant improvements in wildlife risk assessment methods have resulted from this project. First, a database of acute toxicity data for more than 200 chemicals was developed and used to evaluate the sensitivity of birds and mammals to contaminants. Knowing these species sensitivities will result in the selection of more appropriate assessment endpoints in ecological risks assessments. Second, allometric scaling models were developed for each chemical to enable the extrapolation of toxicity values from one species to another. Use of these models reduces the uncertainty associated with limited data and provides a more accurate assessment of the risks to wildlife.

Finally, this project addressed the problem with existing risk assessment methods that can not adequately estimate the relationship between toxic effects on individuals and toxic effects on populations. To address this problem, age-structured and stage-structured matrix models were developed that explicitly include the potential effects of contaminants on growth, reproduction and mortality, and that link these effects to long-term population stability and viability. While current practice assumes that these toxicity test endpoints are equivalent to population-level effects, 100-year simulations with these models demonstrated a scientifically sound approach for realistically extrapolating individual-level effects of contaminants to the population level. Additional knowledge of species sensitivities to chemical contaminants and better models to extrapolate effects between species and from individuals to populations will substantially improve the accuracy of ecological risk assessments by reducing uncertainty, resulting in the more efficient use of limited DOE funds.

RESEARCH OBJECTIVES

The objective of this project is to provide DOE with improved methods to assess risks from contaminants to wildlife populations. The current approach for wildlife risk assessment consists of comparison of contaminant exposure estimates for individual animals to literature-derived toxicity test endpoints. These test endpoints are assumed to estimate thresholds for population-level effects. Moreover, species sensitivities to contaminants is one of several criteria to be considered when selecting assessment endpoints (EPA 1997 and 1998), yet data on the sensitivities of many birds and mammals are lacking. The uncertainties associated with this approach are considerable. First, because toxicity data are not available for most potential wildlife endpoint species, extrapolation of toxicity data from test species to the species of interest is required. There is no consensus on the most appropriate extrapolation method. Second, toxicity data are represented as statistical measures (e.g., NOAELs or LOAELs) that provide no information on the nature or magnitude of effects. The level of effect is an artifact of the replication and dosing regime employed, and does not indicate how effects might increase with increasing exposure. Consequently, slight exceedance of a LOAEL is not distinguished from greatly exceeding it. Third, the relationship of toxic effects on individuals to effects on populations is poorly estimated by existing methods. It is assumed that if the exposure of individuals exceeds levels associated with impaired reproduction, then population level effects are likely. Uncertainty associated with this assumption is large because depending on the reproductive strategy of a given species, comparable levels of reproductive impairment may result in dramatically different population-level responses.

This project included several tasks to address these problems: (1) investigation of the validity of the current allometric scaling approach for interspecies extrapolation and development of new scaling models; (2) development of dose-response models for toxicity data presented in the literature; and (3) development of matrix-based population models that were coupled with dose-response models to provide realistic estimation of population-level effects for individual responses.

Uncertainties associated with the current approach to wildlife risk assessment may have direct impacts on DOE EM satisfactorily fulfilling its mission in two ways. First, risk estimates may be too conservative and therefore remediation may be recommended when it is not needed. It is generally recognized that high uncertainty leads to unnecessary caution in decision-making to avoid adverse consequences (McKelvey 1996; Policansky and Magnuson 1998). Consequently, limited remediation funds may be spent for insignificant or non-existent risks and possibly cause a net increase in environmental damage due to unnecessary habitat destruction. Second, risk estimates may not be adequately protective and therefore remedial actions may not be recommended when they are needed. The consequences of this uncertainty are environmental damage and potential liability in Natural Resource Damage Assessments. Either of these alternatives results in inefficient use of limited EM funds. This project provides the tools to better estimate population-level effects and thereby reduce the uncertainty associated with wildlife risk assessments.

METHODS AND RESULTS

This project consisted of four inter-related tasks, as described below:

1. Development of toxicity data base. A data base of the literature on acute toxicity of chemicals to birds and mammals was developed. Major sources of information included the extensive wildlife toxicity data base from the Denver Wildlife Research Center and the National Institute of Occupational Safety and Health (NIOSH) Registry of Toxic Effects of Chemical Substances. Data on 144 chemicals for birds and 222 chemicals for mammals were obtained and used to evaluate species sensitivities.

2. Development of dose-response models. Wildlife acute toxicity dose-response models were developed to estimate risks to wildlife for a range of exposures when effects data are available for only a partial range of exposures. Following a literature review to define modeling approaches, a protocol was developed to fit 2-, 3-, or 4-parameter logistic models to literature-derived toxicity data. The resulting models were used to define the dose that corresponded with selected levels of effects, and the resulting dose-response models were used in the development of the wildlife population models.

3. Development of improved methods for extrapolation of toxicity between species. One of the existing extrapolation methods, allometric scaling, is based on the premise that the excretion and metabolism of toxic chemicals are a function of metabolic rate, which, in turn, varies as a function of body weight. Using the data base developed as the initial task of the project, linear regression models of lethal dose vs. body weight (using log-transformed data for both variables) were developed for each chemical (Sample and Arenal 1999). To assess species sensitivity, residuals from the allometric scaling

regression models were analyzed (i.e., the difference between the measured value and the value estimated by the regression model; see Figs. 1 and 2). A one-tailed binomials test (Zar 1984) was used to test the frequency of positive residuals (measured toxicity for the test species is underestimated relative to other species in the model, and the species is insensitive) and negative residuals (measured toxicity is overestimated relative to other species in the model, and the species is sensitive). Unlike the patterns of sensitivity among mammalian species, which were relatively constant across chemical classes (e.g., chlorinated hydrocarbons, carbamates, organophosphates, etc.), the patterns of sensitivity of avian species was not constant across chemical classes. The allometric scaling models were used in scaling up from individual to population-level effects in Task 4. Due to the wide variability of scaling factors among chemicals, use of chemical-specific scaling may be more appropriate than one general scaling factor. With these new allometric scaling models, the extrapolation of toxicity effects between species is much improved, thus providing a more accurate assessment of risks when data are limited.

4. Development of population models for wildlife species. Significant uncertainty exists over the occurrence of population-level effects when individual animals are exposed to contaminant concentrations that exceed those associated with impaired reproduction. For example, depending upon the reproductive strategy of a given species, comparable levels of impairment may result in dramatically different population-level responses. To examine this problem, age-based matrix models of representative bird life history strategies and stage-based matrix models of 25 bird species were developed that explicitly included the potential effects of contaminants on fecundity and mortality. Using 100-year simulations, both the age- and stage-based model results showed that the population-level effects inferred from contaminant effects on individuals were often less than the population-level effects predicted by model simulations. These models are valuable tools in assessing the risks of contaminants to wildlife species. The age-based and stage-based modeling approach is highly versatile and flexible. Our analyses demonstrated a scientifically valid approach for realistically extrapolating individual-level contaminant effects to the population level.

RELEVANCE, IMPACT, AND TECHNOLOGY TRANSFER

This project developed new scientific knowledge that addresses the problem of assessing risks of contaminants to wildlife populations. Because remediation at CERCLA sites is based on the assessment of both human health and ecological risks, better ecological assessment methods can reduce uncertainties when data are limited and thus more accurately evaluate remedial action alternatives. Uncertainties may directly impact the fulfillment of the DOE EM mission in two ways. If toxicity values are too conservative, risks to wildlife may be overstated and remediation may unnecessarily be recommended. On the other hand, some toxicity values may not be protective enough, and risks to wildlife will be underestimated; in this case, remedial actions might not be recommended when they are needed. Both alternatives could result in significant increases in cost and schedule without meeting DOE compliance requirements.

This research project utilized basic knowledge about the mechanisms of chemical toxicity and wildlife population dynamics to effectively bridge the gap between basic research and applied technology and produce new methods that can be applied immediately to the risk assessment process. Results from the project can be used by individuals, companies, or institutions that are responsible for waste site remediation, including the assessment of risks. While additional research is needed, as described under Future Work, the risk assessment methods that have been developed from this EMSP project have been published and can be incorporated in CERCLA risk assessments now. Their publication in peer-reviewed journals document their scientific credibility. There are no obvious major hurdles to their widespread acceptance and use. Interest in the results of the project were expressed by the Electric Power Research Institute (EPRI) and a private firm, Applied Biomathematics, Inc., which has extensive experience conducting ecological risk assessments. The company is presently applying the combined matrix modeling and life history theory approach, which was developed in this EMSP project, to fish populations to assess the risks of entrainment and impingement at cooling water intake structures. This EMSP research was also the basis for a new project to extend the matrix modeling approach to include (1) more species, (2) explicit consideration of habitat changes, and (3) other sources of stress or mortality, in addition to entrainment and impingement. This new research will be conducted by one of the EMSP co-principal investigators, Dr. Kenneth Rose, at Louisiana State University.

PROJECT PRODUCTIVITY

The research was completed on schedule without the need for revisions to the work plan. Major products included publications in peer-reviewed journals (two published or in press; two submitted) and two book chapters in a published book. In addition, numerous presentations were made at meetings of technical societies, further enhancing the communication of research results with the scientific community. Finally, the productivity of the project could be measured by the number of graduate students and university faculty who participated in the research. Such collaborations and educational outreach activities benefit the larger research community by communicating new technical advances, such as the innovative improvements in risk assessment methodologies that were developed in this project.

PERSONNEL SUPPORTED

Graduate Students

Shaye Sable, M.S. candidate in oceanography and coastal sciences, Louisiana State University
John Augustine, M.S. candidate in computer science, Louisiana State University
Laura Althauser, M.S. candidate in oceanography and coastal sciences, Louisiana State University

Postdoctoral Student

Courtney Richmond, Philadelphia Academy of Natural Sciences

Visiting Faculty

James Cowan, Professor, University of South Alabama

Post-M.S. Student

Christine Arenal, Oak Ridge National Laboratory (1998-2000)

PUBLICATIONS

Published in Peer-Reviewed Journals and Books

Rose, K. A., L. W. Brewer, L. W. Barnthouse, G. A. Fox, N. W. Gard, M. Mendoca, K. R. Munkittrick, and L. J. Witt. 1999. Ecological responses of oviparous vertebrates to contaminant effects on reproduction and development. IN: P. Albers, G. Heinz, and H. Ohlendorf (eds.). Proceedings of Symposium on Environmental Contaminants and Terrestrial Vertebrates: Effects on Populations, Communities, and Ecosystems, SETAC Press.

Sample, B. E. and C. A. Arenal. 1999. Allometric models for interspecies extrapolation of wildlife toxicity data. Bull. Environ. Contam. Toxicol. 62:653-663.

Sample, B. E., K. A. Rose, and G. W. Suter II. 1999. Estimation of population-level effects on wildlife based on individual-level exposures: Influence of life history strategies. IN: P. Albers, G. Heinz, and H. Ohlendorf (eds.). Proceedings of Symposium on Environmental Contaminants and Terrestrial Vertebrates: Effects on Populations, Communities, and Ecosystems, SETAC Press.

Sample, B. E., C. A. Arenal, and L. K. Mann. In Press. Determination of sensitivity of birds and mammals to environmental contaminants. Arch. Environ. Contam. Toxicol.

Submitted for Publication

Richmond, C., K. A. Rose, and D. Breitburg. Individual variability and environmental conditions: Effects on zooplankton cohort dynamics. Submitted to Oikos.

Sable, S., and K. A. Rose. Relating population responses to stress to life history traits: A stage-based matrix model analysis of bird species. To be submitted to Ecological Modelling or Ecological Applications.

INTERACTIONS

Participation/Presentations at Meetings

Mann, L. K., B. E. Sample, C. Arenal, K. A. Rose, and G. W. Suter II. Estimation of population-level effects on wildlife based on individual-level exposures: Influence of life-history strategies. Poster presentation at Annual Meeting of the DOE Environmental Management Science Program, Atlanta, GA, April 2000.

Rose, K. A. Methods for comparing matrix models to individual-based models. Louisiana Universities Marine Consortium Meeting, July 1999 (invited).

Rose, K. A. Methods for population modeling and predicting population and community responses to stresses such as contaminants. Distinguished Seminar Series, EPA Gulf Breeze Environmental Research Laboratory, August 1999 (invited).

Rose, K. A. Compensatory density-dependence: Importance, controversy, understanding, and prognosis. Platform presentation at the joint EPRI-EPA Workshop on the new 316(b) regulations, Annapolis, MD, January 2001 (invited).

Rose, K. A., P. Thomas, C. A. Murphy, L. A. Fuiman, S. L. Diamond, L. Ford, I. D. McCarthy, I. Khan, and M. C. Alvarez. Using linked simulation models and laboratory studies to determine contaminant effects on fish populations. Platform presentation at Annual Meeting of Society for Environmental Toxicology and Chemistry, Baltimore, MD, November 2001 (invited).

Richmond, C., K. A. Rose, and D. Breitburg. The role of individual variability in population dynamics under changing environmental conditions. Platform presentation at Annual Meeting of the Ecological Society of American, Spokane, WA, August 1999.

Sable, S., K. A. Rose, and J. E. Augustine. Influence of life history strategies on bird population responses to stress. Platform presentation at Annual Meeting of the Ecological Society of America, Snowbird, UT, August 2000.

Sample, B. E., K. A. Rose, and G. W. Suter II. Estimation of potential population-level effects of contaminants on wildlife. Poster presentation at Annual Meeting of the DOE Environmental Management Science Program, Chicago, IL, July 1998.

Sample, B. E., K. A. Rose, and G. W. Suter II. Estimation of population-level effects on wildlife based on individual-level exposures: Influence of life history strategies. Platform presentation at Symposium on Environmental Contaminants and Terrestrial Vertebrates: Effects on Populations, Communities, and Ecosystems, College Park, MD, October 1998.

Sample, B. and C. Arenal. Allometric models for interspecies extrapolation of wildlife toxicity data: Expanding the database. Poster presentation at Annual Meeting of the Society for Environmental Toxicology and Chemistry, Charlotte, NC, November 1998.

Sample, B. E., K. A. Rose, G. W. Suter II, and C. Arenal. Wildlife toxicity data and ecological risk assessment: Problems and solutions. Platform presentation at Annual Meeting of the Society for Environmental Toxicology and Chemistry, Charlotte, NC, November 1998.

Sample, B. E., K. A. Rose, and G. W. Suter II. Estimation of potential population-level effects of contaminants on wildlife. Poster presentation at Partners in Environmental Technology 98: SERDP Symposium and Workshop, Crystal City, VA, December 1998 (invited).

Sample, B. E., K. A. Rose, and G. W. Suter II. Estimation of potential population-level effects of contaminants on wildlife. Platform presentation at Annual Meeting of the Society for Environmental Toxicology and Chemistry Meeting (NorCal Chapter), Concord, CA, April 1999 (invited).

Sample, B. E., C. Arenal, and L. K. Mann. Determination of sensitivity of birds and mammals to environmental contaminants. Poster presentation at Annual Meeting of the Society for Environmental Toxicology and Chemistry, Philadelphia, PA, November 1999.

Sample, B. E. and C. Arenal. Species sensitivity analyses. Poster presentation at Annual Meeting of The Wildlife Society, Nashville, TN, September 2000.

Consultative and Advisory Functions to Other Laboratories and Agencies

Glenn Suter, EPA Science Advisor on Risk Assessment, was contacted by Brad Sample in September 1999 for guidance on future directions and requirements for wildlife risk assessment. Results from this telephone conversation were used to assess future research needs related to wildlife risk assessment.

Clarence Callahan and Ned Black, EPA-Region 9; Regina Donahoe, California Office of Environmental Health and Hazard Assessment; and Jim Polisini, California Department of Toxic Substance Control, were contacted by telephone and at technical meetings in 1999-2000 by Brad Sample to discuss scaling factors for wildlife risk assessment. The EMSP principal investigator (Brad Sample) had published papers in peer-reviewed journals on this topic.

Bruce Hope, Ecorisk-Oregon Department of Environmental Quality, was called several times in 1999-2000 by Brad Sample for guidance to ensure that the wildlife risk assessment tools were suitable for regional applications.

John D. Eisemann, Natuibak Wildlife Research Center (USDA APHIS); Rick Bennett, Head of Wildlife Toxicology-EPA Duluth Laboratory; and Pierre Mineau, Canadian Wildlife Service, were consulted via conference call by Brad Sample in March 2000 on digitizing and upgrading the Denver National Wildlife Research Center chemical toxicity data base to improve its utility to end users.

Collaborations

Nathan Schumaker, EPA-Corvallis, was contacted by Brad Sample and Kenny Rose via telephone and email on several occasions between 1998 and 2000 to discuss the use of the EPA PATCH model in the EMSP project and the benefits to DOE of this collaboration.

Pierre Mineau, Canadian Wildlife Service, was consulted several times in 1999 by telephone by Brad Sample to discuss additional research on interspecies scaling.

Edward Chesney, Louisiana Universities' Marine Consortium, invited Kenny Rose to give a seminar in July 1999, comparing matrix and individual-based models, including his EMSP research.

James Cowan, Dauphin Island Sea Laboratory, invited Kenny Rose to give a seminar in July 1999 on the strengths and weaknesses of population modelling, which included the matrix bird models that were developed in the EMSP project.

Kevin Summers, Associate Director for Science-EPA Gulf Breeze Environmental Research Laboratory, invited Kenny Rose to give a seminar in August 1999 on population modeling, including his EMSP research.

Douglas Dixon, Electric Power Research Institute, and Kenny Rose had numerous discussions concerning the application of the EMSP bird analyses to fish in order to better predict population-level risks associated with power plant operations.

TRANSITIONS

The population matrix models that were developed to assess risks of contaminants to wildlife populations will be modified to include other risks and additional species. At the request of the Electric Power Research Institute (EPRI), the modeling approach will be expanded to fish populations to assess the risks of entrainment of fish eggs and larvae and of the impingement of juvenile and adult fishes. These are sources of mortality associated with the withdrawal of large volumes of cooling water by electrical generating plants. The research will be conducted by a private company, Applied Biomathematics, Inc. Results of the EMSP project also led to new studies that will be funded by EPRI but conducted by one of the project's co-principal investigators, Dr. Kenneth Rose. Dr. Rose was invited to attend a joint EPA-EPRI workshop on the new requirements under Section 316 of the Clean Water Act, and gave a presentation on his EMSP research. The new work will be funded by EPRI (Dr. Douglas Dixon, Program Manager) and will extend the EMSP study to include other species, explicit consideration of habitat, and other sources of mortality, in addition to entrainment and impingement.

PATENTS

None.

FUTURE WORK

To illustrate the importance of modeling population-level responses, a case study is planned, using contaminant effects on mink to compare traditional and population dynamics-based approaches to risk assessment. Additional research is needed to expand the framework for risk assessment that was developed in this project. The logical next steps for improving methods for assessing risks to wildlife populations are (1) expansion of the dose-response data base and models to include dermal and respiratory exposure routes and (2) enhancements to the population models to investigate the indirect effects from prey and spatial influences on risk. Results of these proposed investigations will further reduce the uncertainty associated with ecological risk assessments and improve the scientific basis for evaluating remedial action alternatives.

LITERATURE CITED

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Policansky, D. and J. J. Magnuson. 1998. Genetics, metapopulations, and ecosystem management of fisheries. Ecol. Appl. 8(Supplement):S119-S123

Sample, B. E. and C. A. Arenal. 1999. Allometric models for interspecies extrapolation of wildlife toxicity data. Bull. Environ. Contam. Toxicol. 62:653-663.

U.S. Environmental Protection Agency (EPA). 1997. Ecological risk assessment guidance for Superfund: Process for designing and conducting ecological risk assessments. Interim Final. U.S. Environmental Protection Agency, Emergency Response Team.

U.S. Environmental Protection Agency (EPA). 1998. Guidelines for ecological risk assessment. EPA/630/R-95/002F. Risk Assessment Forum, Washington, DC.

Zar, J. H. 1984. Biostatistical Analysis. Prentice-Hall, Inc. Englewood Cliffs, NJ. 718 pp.

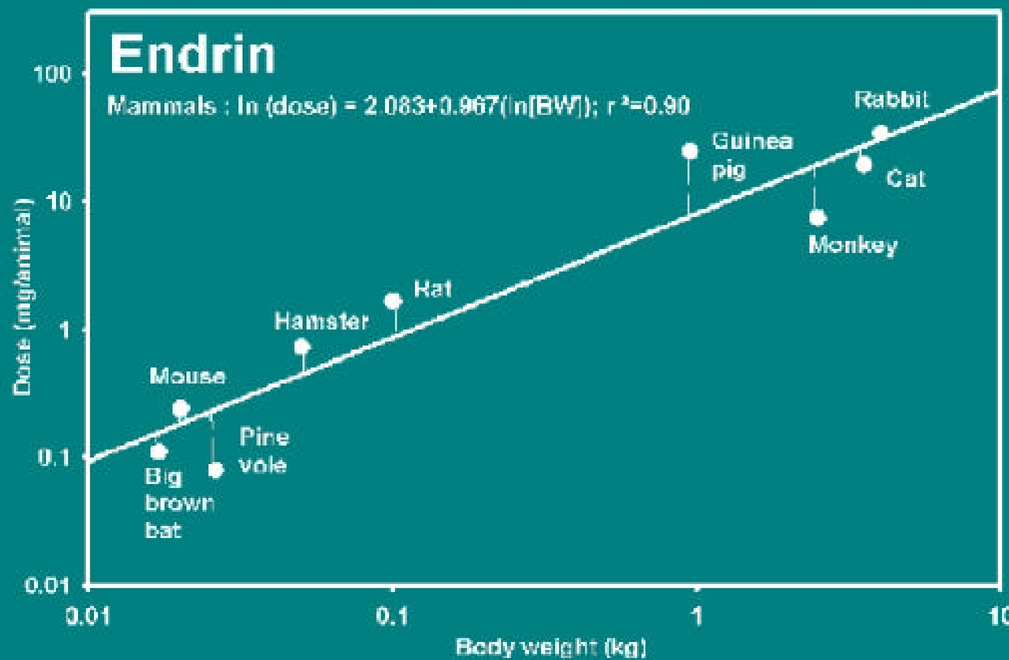

Figure 1. Allometric scaling regression and residuals for endrin in mammals.

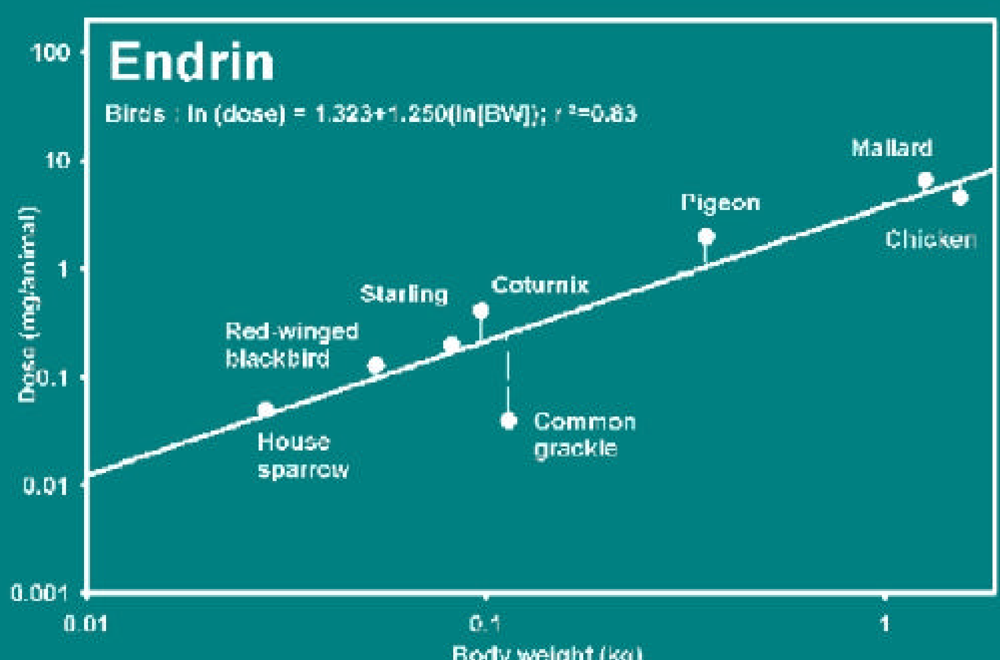

Figure 2. Allometric scaling regression and residuals for endrin in birds.