

“Selective” Pesticides: Are They Less Hazardous to the Environment?

JOHN D. STARK AND JOHN E. BANKS

For half a century, scientists and the public have been well aware of the risk posed by pesticides to humans and the environment. Worldwide concern about pesticide residues on food and in drinking water has led to legislative efforts to restrict the use of traditional, broad-spectrum pesticides. In the United States, the Food Quality Protection Act (Public Law 104-170), passed by Congress in 1996, effectively mandates a severe reduction in the use of many such pesticides for a wide range of agricultural uses. The principal rationale for restricting the use of many of these chemicals is to protect consumers, especially children, who are judged to be more susceptible to the effects of pesticides (NRC 1993, Goldman 1998).

For their part, in anticipation of the loss of many widely used organophosphorus and carbamate insecticides, pesticide producers have developed a suite of new biorational pesticides designed to target only select organisms. These new products are typically termed *selective* based on the results of simple laboratory dose–response trials with target and nontarget species to determine LD_{50} , the dose of a chemical that kills 50% of the population tested (LD = “lethal dose”). There is increasing evidence that many nontarget species are affected by several of these chemicals in ways that are often surprising and unpredictable (Banken and Stark 1998, Boyd and Boethel 1998, Losey et al. 1999, Smith and Krischik 1999).

Unfortunately, little effort has been directed toward developing alternative measures of toxicity of these new chemicals and then using them in risk assessment. Thus, we set out to quantify the extent to which these new chemicals may be lethal to nontarget organisms. We compared the toxicity of six new selective insecticides to the toxicity of a widely used, broad-spectrum, representative organophosphorus insecticide (diazinon). In addition, we used two toxicological endpoints in a simplistic hazard assessment exercise. The first hazard assessment was performed using the traditional LC_{50} method (LC_{50} is a statistical estimate of the concentration, in a medium such as water, that kills 50% of the population); the second was done using a measure of population growth

rate and estimating the concentration that caused population extinction.

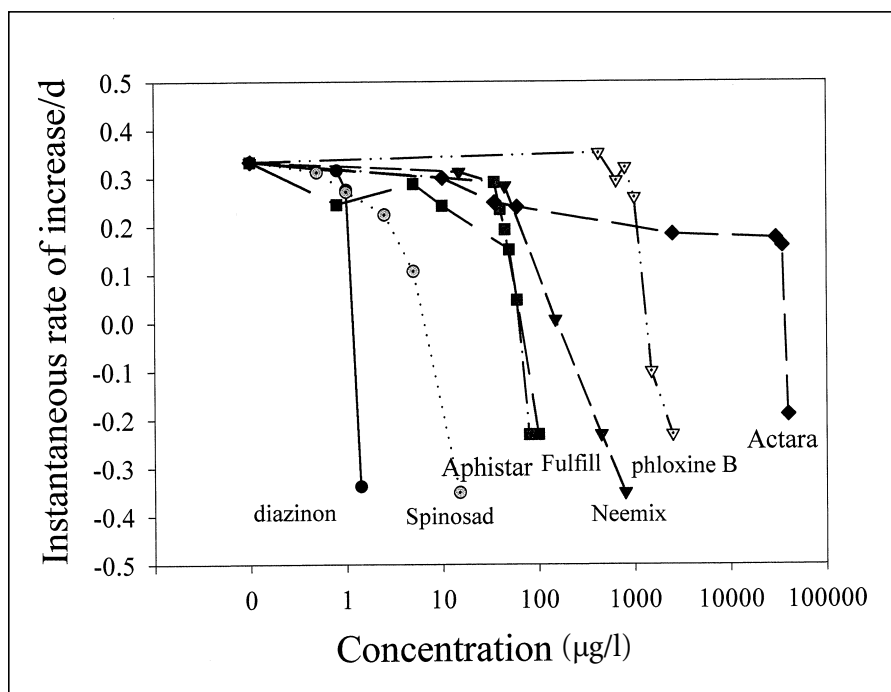
We focused on insecticides in this study because they represent a larger threat to biological communities and the environment than fungicides and herbicides (Croft 1990). We chose to assess the impacts of insecticides on an aquatic species, the Cladoceran *Daphnia pulex* (Walthall and Stark 1998). This animal is widely studied and is commonly used as an indicator species for environmental contaminants (USEPA 1991).

We developed acute (48 hours) lethal concentration estimates (LC_{50}) and a 10-day measure of population growth rate, the instantaneous rate of increase (Walthall and Stark 1997) for the following insecticides: diazinon, spinosad, Neemix 4.5, phloxine B, Fulfill, Aphistar, and Actara (Figure 1). All of these insecticides are relatively new, except for diazinon, a widely used organophosphorous neurotoxin that is a common contaminant found in aquatic systems (Gilliom et al. 1999, USGS 1999).

Extinction concentrations were generated by regression analysis on population growth rate–concentration data (Figure 1), in which the extinction threshold was defined as a growth rate of -0.01 . Substitution of the extinction threshold into regression equations resulted in a corresponding extinction concentration (x -axis intercept of regression line) for each chemical tested.

Because environmental concentration data for the new selective insecticides are limited, we modified a hazard assessment technique geared toward direct applications of chemicals into a body of water (AAFC 1993). The technique involves the use of the expected environmental concentration

John D. Stark (e-mail: stark@puyallup.wsu.edu) is a professor in the Ecotoxicology Program, Department of Entomology, Washington State University, Puyallup, WA 98371-4998. John E. Banks is an assistant professor in Interdisciplinary Arts and Sciences, University of Washington, Tacoma, WA 98402-3100. © 2000 American Institute of Biological Sciences.



Comparison of instantaneous rate of increase for *Daphnia pulex* exposed to diazinon and a suite of selective pesticides. Instantaneous rates of increase/d is a measure of population growth rate 10 days after the start of the experiment (see Walthall and Stark 1997 for details).

(EEC), which is defined as the concentration of pesticide in 150 liters of water after direct application on a forest at the maximum application rate. To develop the EEC, we used the average foliar application rate (Table 1) instead of the maximum rate. To determine the average, we calculated the mean of the lowest and highest recommended application rates

Table 1. Average foliar application rates and expected environmental concentrations of insecticides evaluated in the hazard assessments.

Chemical	Average foliar application rate (mg active ingredient per m ²)	EEC ¹ (mg per l)
Diazinon	237.8	1.585
Actara	6	0.040
Aphistar	0.028	0.186
Fulfill	21	0.140
Neemix	5	0.033
Phloxine B	14.6	0.097
Spinosad	0.2	0.068

1. EEC is the concentration of pesticide in 150 l of water after a direct over spray of a forest at the average foliar application rate.

given by manufacturers or listed in *Crop Protection Reference* (1998). EECs used in the hazard assessments are shown in Table 1. Hazard quotients were generated by dividing the EEC by the LC₅₀ or population extinction concentration. Hazard quotients greater than 1 indicate that a chemical may cause damage to an ecosystem (Suter 1993).

Acute LC₅₀ assessments indicated that all the new insecticides were significantly less toxic than diazinon ($p < 0.05$) (Table 2). Hazard assessment based on the LC₅₀ suggests that none of the new insecticides posed a hazard to *D. pulex* except for the acetylcholinesterase inhibitor Aphistar (Table 3). In contrast, hazard assessment based on a concentration that would cause extinction indicated that most of the new insecticides pose a hazard to *D. pulex* (Table 3). Actara was borderline with a hazard quotient of 1, and phloxine B was far below the environmental hazard threshold.

The traditional LC₅₀ measure indicated that the least toxic selective insecticide was Actara, at approximately 6.6×10^4 times less toxic than diazinon (Table 2). On the other hand, the extinction

concentration indicated that Actara was only 22 times less toxic than diazinon. Hazard quotients generated using two different toxicological endpoints spanned three orders of magnitude, varying from 1.5- to 1122-fold (Actara). For some insecticides, both hazard quotients gave similar results (Aphistar and phloxine b), but for others, huge differences were present (Actara, Fulfill, Neemix, and spinosad; Table 3).

Population extinction concentrations for the new selective insecticides ranged from 3 to 406 times less than diazinon. With such variable patterns of relative toxicity, it is evident that generalizations about the toxicity of the new generation of selective pesticides may be premature.

The differences we found between LC₅₀ and population extinction-based risk assessments serve as a cautionary tale for those establishing toxicological protocols for these new chemicals. Furthermore, they highlight the need to more carefully screen the full range of effects that chemicals may have at both the individual and population levels. While the more simplistic (and standard) LC₅₀ analysis indicates that the new insecticides pose little hazard to *D. pulex*, the population extinction analysis reveals a substantially greater overall menace. Field studies have further indicated that the ability to predict how organisms will respond to selective pesticides becomes even more challenging in the context of biological communities, including target and nontarget organisms along with their suite of natural enemies (Banks and Stark 1998).

Table 2. Acute (48h) lethal concentration estimates for *Daphnia pulex* exposed to different insecticides.

Chemical	Number tested	Slope + SE	LC ₅₀ ^a with 95% fiducial limits (mg per l)
Diazinon	210	2.34 ± 0.27	0.00062 (0.00056–0.00070)
Actara	100	9.1 ± 2.0	41 (37.6–45.7)
Aphistar	125	8.8 ± 1.8	0.053 (0.047–0.057)
Fulfill	210	0.72 ± 0.11	0.165 (0.077–0.325)
Neemix	100	8.09 ± 1.55	0.680 (0.595–0.748)
Phloxine B	320	3.6 ± 0.37	0.423 (0.376–0.477)
Spinosad	320	1.01 ± 0.17	0.129 (0.077–0.181)

Note: See Walthall and Stark 1997 for the full description of methods of toxicity testing.

Table 3. Hazard of insecticides to *Daphnia pulex*.

Chemical	Extinction concentration (mg per liter)	Hazard quotient based on population extinction	Hazard quotient based on LC ₅₀ ¹	Difference in hazard quotients (percentage)
Diazinon	0.0016	991.0	2,556	2.58
Actara	0.035	1.1	0.00098	1122.45
Aphistar	0.035	5.3	3.55	1.49
Fulfill	0.005	28.0	0.851	32.90
Neemix	0.015	2.2	0.049	44.90
Phloxine B	0.65	0.15	0.23	0.65
Spinosad	0.007	9.7	0.527	18.41

1. This assessment takes into account both toxicity and potential exposure based on average spray application rates. Hazard quotients were generated by dividing the expected environmental concentration by LC₅₀ or population extinction measures for each chemical. Hazard quotients equal to or less than 1 indicate that the chemical poses a risk.

Acknowledgments

We thank Peter Kareiva (National Oceanic and Atmospheric Administration, Seattle) for his valuable comments and suggestions regarding the manuscript. We also thank Grace Jack, William Walthall, and Barbara Wood for help in collecting data.

References cited

- [AAFC] Agriculture and Agri-Food Canada. 1993. Registration guidelines for microbial pest control agents. Ottawa, Ontario: Plant Industry Directorate, AAFC. Bulletin Pro93-04.
- Banken JAO, Stark JD. 1998. Multiple routes of pesticide exposure and the risk of pesticides to biological controls: A study of neem and the seven-spot lady beetle, *Coccinella septempunctata* L. *Journal of Economic Entomology* 91: 1–6.
- Banks JE, Stark JD. 1998. What is ecotoxicology? An ad-hoc grab bag or an interdisciplinary science? *Integrative Biology* 1: 195–204.
- Boyd ML, Boethel DJ. 1998. Residual toxicity of selected insecticides to Heteropteran predaceous species (Heteroptera: Lygaeidae, Nabidae, Pentatomidae) on soybean. *Environmental Entomology* 27: 154–160.
- Croft BA. 1990. *Arthropod Biological Control Agents and Pesticides*. New York: John Wiley and Sons.
- Crop Protection Reference, 14th ed. 1998. New York: C&P Press.

- Gilliom RJ, Barbash JE, Kolpin DW, Larson SJ. 1999. Testing water quality for pesticide pollution. *Environmental Science and Technology* 4: 164a–169a.
- Goldman LR. 1998. Linking research and policy to ensure children's environmental health. *Environmental Health Perspectives* 106 (supplement 3): 857–862.
- Losey JE, Rayor LS, Carter ME. 1999. Transgenic pollen harms monarch larvae. *Nature* 369: 214–216.
- [NRC] National Research Council. 1993. *Pesticides in the diets of infants and children*. Washington (DC): National Academy Press.
- Smith SF, Krischik VA. 1999. Effects of systemic Imidacloprid on *Coleomegilla maculata* (Coleoptera: Coccinellidae). *Environmental Entomology* 28: 1189–1195.
- Suter, GW II. 1993. *Ecological Risk Assessment*. Boca Raton (FL): Lewis Publishers.
- [USEPA] US Environmental Protection Agency. 1991. *Methods for measuring the acute toxicity of effluents and receiving waters to freshwater and marine organisms*. Cincinnati (OH): USEPA. EPA/600/4-90/027.
- [USGS] US Geological Survey. 1999. *The quality of our nation's waters: Nutrients in pesticides*. Reston (VA): USGS. Circular no. 1225.
- Walthall WK, Stark JD. 1997. Comparison of two population-level ecotoxicological endpoints: The intrinsic (rm) and instantaneous (ri) rates of increase. *Environmental Toxicology and Chemistry* 16: 1068–1073.
- . 1998. The acute and chronic toxicity of two xanthene dyes, fluorescein sodium salt and phloxine B, to *Daphnia pulex* (Leydig). *Environmental Pollution* 104: 207–215.

The complete source on all of the important aspects of biology!

FRONTIERS of LIFE

FOUR-VOLUME SET

Frontiers of Life addresses fields of biology in terms of their frontiers—that is, the areas that will demand the most work in this new century. Because of their standing, the editors have been able to unite the most prestigious and well-informed authorities to place recent scientific advances into the context of their effects on daily human experiences and expectations. They ask, “what frontiers of the biological sciences will constitute the challenges of the next century?” Their first answer is an understanding of the processes and mechanisms that led to the origin of life. They take this answer as the starting point of the first section of the **Encyclopedia**.

Separating this encyclopedia from others is its multidisciplinary approach to the “frontiers” theme. While other encyclopedias strive to describe the past and present states of many subjects, **Frontiers of Life** offers the insights of world-class scientists into their subjects’ growth areas.

All Prices and publication dates subject to change without notice. ©2001 by Academic Press. All Rights Reserved. MC/EA/SBE-06011 7/01

★★★ FOUR COLOR THROUGHOUT!

Edited by
David Baltimore
California Institute of Technology, Pasadena, USA
Renato Dulbecco
The Salk Institute, La Jolla, California, USA

François Jacob
Pasteur Institute, Paris, France
Rita Levi-Montalcini
The Neurobiology Institute of CNR, Rome, Italy

ORDER

from your favorite bookseller or directly from:

In the U.S. and Canada:
ACADEMIC PRESS
Order Fulfillment Dept.
DM27101
6277 Sea Harbor Drive
Orlando, FL 32887
Call Toll Free: 1-800-321-5068
Fax: 1-800-874-6418
E-mail: ap@acad.com

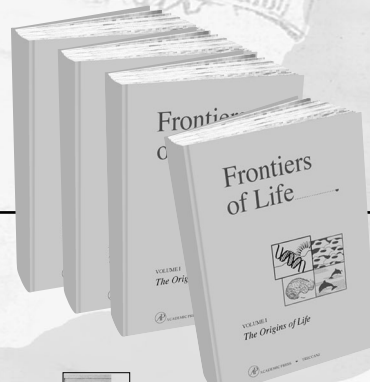
All other countries:
HARCOURT PUBLISHERS LTD
Customer Service Dept.
Foots Cray High Street
Sidcup, Kent DA14 5HP, UK
Tel: +44 (0)20 8308 5700
Fax: +44 (0)20 8308 5702
cservice@harcourt.com



ACADEMIC PRESS

A Harcourt Science and Technology Company

Find us on the web! • SECURE ORDERING ONLINE
www.academicpress.com • www.harcourt-international.com



★★★★

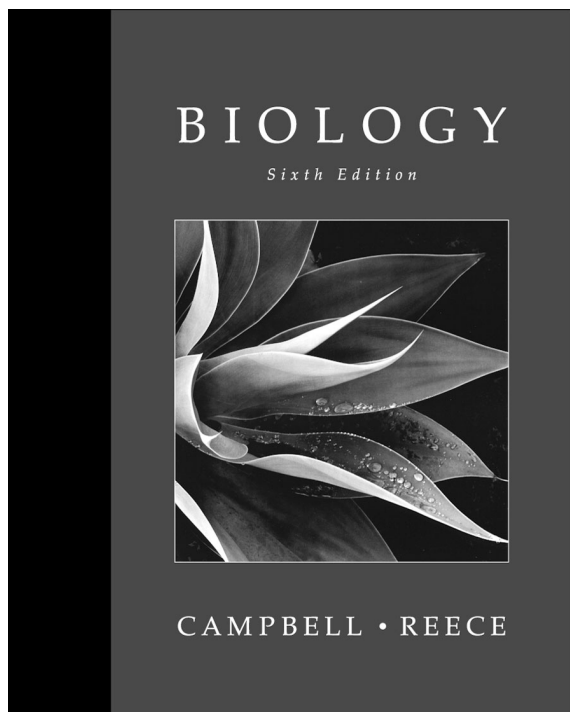
Four-Volume Set
Introductory Price: 1,350.00/£900.00*

October 2001, c. 3100 pp.,
\$1,800.00/£1,200.00
ISBN: 0-12-077340-6

*Introductory price valid up to three months after month of publication.

Note: *Frontiers of Life* is an updated translation of *Frontiere della Vita*, published by the Istituto della Enciclopedia Italiana Treccani.

THE EVOLUTION OF A MASTERPIECE



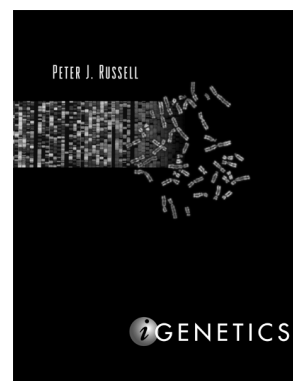
BIOLOGY, Sixth Edition
NEIL CAMPBELL AND JANE REECE
0-8053-6624-5

With **BIOLOGY, Sixth Edition**, authors Neil Campbell and Jane Reece have once again crafted a synthesis of modern biology that you and your students can depend on for clear explanations, innovative illustrations, and scientific accuracy.

Please visit www.aw.com/bc/info/campbell6e for more information.

CAMPBELL • REECE

Also new from Benjamin Cummings:
iGenetics by Peter J. Russell



0-8053-4553-1

iGenetics is the first integrated text with all text, art, and media created to provide a balanced introduction to genetics. Building on the proven strength of Peter J. Russell's step-by-step problem-solving approach, *iGenetics* takes a modern, molecular approach. The book covers basic genetics principles, with balanced coverage of Mendel, historical experiments, and cutting-edge chapters on genomics and molecular evolution.

Please visit www.aw.com/bc/info/russell for more information.



www.aw.com/bc