inherent variability in natural systems. Nevertheless they will provide a general framework for developing methods to help identify which processes to focus on when trying to translate results measured at one spatial/temporal scale to another.

This work, which is being carried out with funding from the Foundation for Research, Science and Technology, aims to improve our understanding of the variability inherent in water resources. It should enable us to provide a scientific basis for models of river basin processes that can reliably convert information on river flow in one basin into the corresponding information in a different basin. ■

Richard Ibbitt is based at NIWA in Christchurch.

Further reading

Costa-Cabral, M.C. and Burges, S.J. 1997. Sensitivity of channel network planform laws and the question of topologic randomness. *Water Resources Research 33* (9): 2179–2197.

Robinson, J.S., Sivapalan, M. and Snell, J.D. 1995. On the relative roles of hillslope processes, channel routing, and network geomorphology in the hydrologic response of natural catchments. *Water Resources Research 31*(12): 3089–3101.

Snell, J.D. and Sivapalan, M. 1994. On geomorphological dispersion in natural catchments and the geomorphological unit hydrograph. *Water Resources Research 30*(7): 2311–2323.

Willgoose, G.R. 1994. A statistic for testing the elevation characteristics of landscape simulation models. *Journal of Geophysical Research 99*(B7): 13,987–13,996.

STATISTICAL METHODS

Detecting environmental impacts

Judi Hewitt

Vonda Cummings

Effective environmental monitoring calls for appropriate study designs and data analyses; NIWA studies have identified that some methods can work better than others.

MAINTAINING ENVIRONMENTAL quality has become an important aspect of development and other activities in New Zealand, with the philosophy encompassed in our Resource Management (RMA) legislation.

An integral aspect of the RMA is the aim of "no significant impact" on the environment. This implies an ability to determine whether any particular activity does have an impact. But how can we decide whether an environmental change really is caused by a particular activity?

The main difficulty is that the environment is naturally variable. For example, types and numbers of shellfish in an estuary may vary both from place to place, and at the same place at different times. Thus the problem is how can we distinguish this natural variability from the changes which result from some human activity (e.g., catchment clearing, sewage discharge). Even if it were possible to separate the two, we would still need to be able to determine whether the change associated with the activity is statistically and ecologically significant.

It is important to design and analyse studies carefully and efficiently when investigating environmental effects so that we can be objective and cost-effective in our assessment of change. For scientists or managers addressing the problem of ecological impacts, there is a growing wealth of design and analysis tools. How do we decide which are the best ones to use?

Sampling and site selection: what are the problems?

To determine whether a particular activity has made any difference to the environment, it is necessary to take samples both before (B) and after (A) an "impact" occurs. This experimental design is known as "BA".

However, if samples are taken at only one time before and after the impact there is no guarantee that any differences detected are caused by the impact. The change may be natural variability over time. To overcome this, samples could be taken several times before and after the impact.

An additional site may be introduced to act as a "control". In this case the design is called "BACI" (i.e., Before and After; Control vs Impact).

The control site must be as similar as possible to the impact site in its physical characteristics, in the external environmental factors acting on it, and in the plant and animal life inhabiting the site. At the same time, it must be located sufficiently far from the impact site that it is not influenced by the suspected impact.

Unfortunately, even assuming that these control-site criteria can be met (and this is by no means a simple task in real-world situations) it could still be claimed that any difference detected between the control and impact sites may be due to some temporal variability that just happened to occur at either site at the same time as the impact. One way around this problem would be to have multiple control sites – but finding just one control site can be very difficult. And as the impact and control sites become more distant, they will tend to have fewer similarities, making impacts even harder to detect.

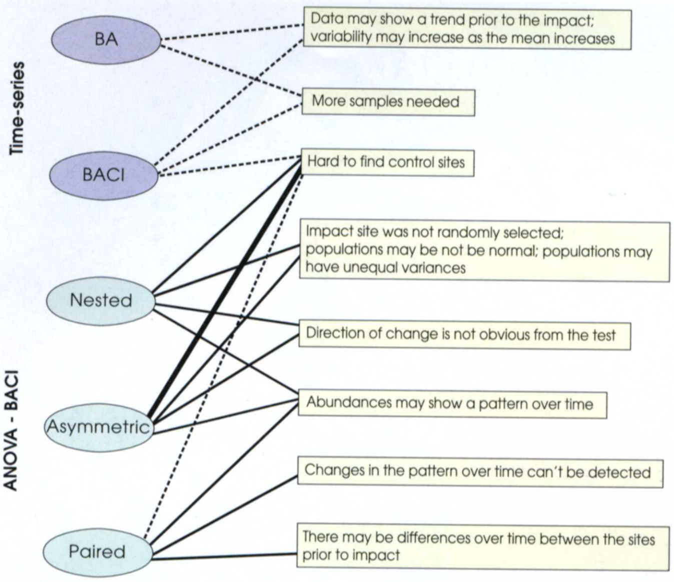
The use of controls is just one method of strengthening causal inference. Other techniques include:

- understanding the mechanisms that cause the effect;
- measuring a particularly strong effect;
- finding consistency with other studies of the effect;

Recommended statistics textbooks

Chatfield, C. 1980. "The analysis of time series: an introduction". Chapman and Hall.

Zar, J.H. 1996. "Biostatistical analyses". Prentice-Hall.



above:

Common analyses and their problems. Lines are used to connect the analysis to an associated problem. The line type indicates how serious we found the problem to be:

dashed	*theoretically there should be a problem but we didn't find one.*
thin line	*problem found*
thick line	*problem worse for this analysis*

Common types of ANOVA

nested ANOVA: rather than looking for an overall effect of time, any effect that time may have is considered to be occurring within the effects of period (before and after) and location (impact and control).

asymmetric ANOVA: nested ANOVA analysing data from one impact site and many control sites.

paired ANOVA: differences between a single impact site and a single control site are calculated and tested to see whether the differences before the impact are similar to those afterwards.

- looking for and detecting a gradient of effects;
- finding that the cause precedes the effect;
- having other sources of knowledge in which similar impacts lead to similar effects.

Analysing results

The statistical analysis of environmental impact data commonly involves either some form of analysis of variance (ANOVA) or time-series analysis.

ANOVA is a powerful tool developed for testing the equality of means in an experimental situation. Briefly, the datasets you wish to compare are characterised by a variance and then tested to see if it is likely that they could all be part of a bigger dataset with a similar variance. ANOVA requires that each dataset be approximately characterised by a bell-shaped curve (i.e., the data are "normal") and that the variances for each dataset not be widely different.

Adapting ANOVA for non-experimental problems (i.e., detecting environmental impacts) has been difficult. As a result, many different forms of ANOVA for detecting impacts have evolved, each one attempting to solve a problem or problems identified from a previous analysis (see panel for examples). ANOVA is thought to require fewer samples, collected over shorter time periods than the alternative, time-series analysis.

Time-series analysis is the analysis of data collected at equally spaced time intervals, using techniques which take advantage of any cyclic patterns over time in the dataset (e.g., seasonal changes in temperature). These days such patterns can easily be identified and modelled using a variety of statistical packages. Time-series analysis requires that the variance of a cycle does not increase as the mean of the cycle increases. For example, this requirement would not be met if the variability in temperature became greater in a hotter-than-average year.

Time-series analysis requires at least 30 data points in time, and more than 5 replicates collected at each time are usually needed to provide good estimates of the mean. However, the advantage of time-series analysis is that it was designed to assess the natural variability of populations over time. Thus, separating natural from impact-associated variability is easier than when ANOVA is used. It also is less likely to force you to presuppose that you know the time period of response to the impact. This technique is frequently used for analysis of monitoring programmes and the combination can provide a useful tool for detecting large-scale impacts.

Our study

We are presently using macrofaunal data collected from four physically similar sites in one harbour to test the best way of analysing data for impact assessments. To simulate impacts of various sizes and types, abundances of selected species at one of the sites were changed. Some of the most frequently used time-series and ANOVA analyses were then conducted and the results compared (see figure).

Our results so far

- It was more difficult to satisfy the requirements of the ANOVA tests than the requirements of time-series analysis (see above and figure for requirements).
- The ANOVAs were much less sensitive than time-series. Out of 10 species undergoing a two-thirds decrease in abundance, each of the ANOVA methods only detected a change in one of these species. The time-series methods detected changes in between three and five of the species and often could detect a lower change (e.g., a one-third decrease or even a one-tenth decrease).
- Finding sufficiently similar control sites was difficult.

This is preliminary work and several other methodologies remain to be investigated. For example, samples can be collected at increasing distances from a suspected impact source and analysed by regression (gradient analysis). Also the field of Bayesian statistics may be helpful. Bayesian statistics allow any prior knowledge of the effect of the suspected impact to be used when calculating the likelihood of the impact having occurred. This can help us determine the ecological significance of changes and strengthen the inferences, especially where control sites are hard to find. ■

Judi Hewitt and Vonda Cummings are based at NIWA in Hamilton.

For further information, contact:

Judi Hewitt, NIWA, PO Box 11,115, Hamilton
Phone: 07 856 7026; Fax: 07 856 0151;
email: j.hewitt@niwa.cri.nz