Large Scale Ecological Studies and their Importance for Freshwater Resource Management

Report of a Forum held at Bayview Conference Centre, Monash University, 15th December 2000

Peter Cottingham, Stephen Carpenter, Ray Hilborn, Jim Kitchell and Craig Stow

Technical Report No. 4/2001

Cooperative Research Centre for Freshwater Ecology

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The Cooperative Research Centre for Freshwater Ecology is a national research centre specialising in river and wetland ecology. The CRC for Freshwater Ecology provides the ecological knowledge needed to help manage the rivers in a sustainable way. It was established in 1993 under the Australian Government's Cooperative Research Centre Program. In the CRC, university, government and industry partners work together to understand river systems.

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1 INTRODUCTION

Issues such as increasing and widespread salinity in rivers, or the vulnerability of many native fish populations, have highlighted the fact that the sustainable management of our water resources must have a large-scale, long-term perspective. Unfortunately, the ecological information available to support decision-making at large scales (e.g. river catchment, basin or regional level) and over long time frames (decades) is very limited. Traditionally, scientists who study key ecological issues and processes have done so at small, well controlled scales (e.g. local site or river reach; days, weeks, seasons) so that they can be confident of their research results and conclude their studies within the time constraints of research grants. Often the results of research undertaken at small scales do not lend themselves to application at large scales or in different locations. It is therefore important that the questions underpinning research, and the decision-making process in which answers are to be applied, are clear or are pitched at the scale of management. This will help to avoid any mismatch in the scale of research that may limit its usefulness in large-scale management decision making.

Experience overseas has shown that it is possible to design and conduct large-scale, long-term ecological experiments to inform decision making in water resource management. Long-term ecological studies can be performed as ‘management experiments’, where rigorous scientific method is used to evaluate the effects of key management actions. The results can then be used to refine future management approaches.

The CRC for Freshwater Ecology convened a one-day forum to explore how management questions and problems might be framed scientifically and how ecological studies can be designed to provide information for the effective long-term management of our water resources. The forum was supported by the expertise and experience of the internationally recognised ecologists whose presentations form the basis of the following chapters of this report:

- Professor Jim Kitchell (University of Wisconsin) – Can large systems be manipulated?
- Professor Stephen Carpenter (University of Wisconsin) – Characteristics of successful experiments.
- Professor Craig Stow (Duke University) – Long term monitoring: nutrient loading in the Neuse River.
- Professor Ray Hilborn (University of Washington) – Adaptive Management.

2 CAN LARGE-SCALE ECOSYSTEMS BE MANIPULATED?

Ecosystem experiments in large-scale systems gained international prominence in the 1980's. Of particular note were the series of comparisons, ecosystem experiments and simulation analyses of the trophic cascade effect in North American lakes (Carpenter and Kitchell 1993a). This, and other examples of manipulation at large scales, are discussed briefly below, including ecosystem experiments in Lake Mendota and Lake Michigan, and observations of pink salmon stocks in the northern Pacific Ocean.

Large-scale experimentation has a human element to it. For example, we hear of the experiments that work, but less so of the experiments that fail. However, there is much that can be learned from experiments that don't go as planned. Some of the lessons learnt from experiments that did not go according to plan are considered below. It should also be recognised that securing long term resources for experimentation requires research to be relevant to those who will ultimately use the results. The history of large-scale experimentation in North America (e.g. the Experimental Lakes Area in Canada) suggests that long-term partnerships between managers and scientists increase the potential for learning at scales relevant to the management of natural resources.

2.1 Peter, Paul and Tuesday Lakes

Whole lake manipulations played an integral part in the experimentation that formed the trophic cascade work reported by Carpenter and Kitchell (1993a). Lakes Peter, Paul and Tuesday are part of an Environmental Research Centre owned by the University of Notre Dame. Fish populations were manipulated in Lakes Peter and Tuesday, while Lake Paul was used as a reference against which to assess the results of manipulation in Lakes Peter and Tuesday.

The basic premise of trophic cascades is that size-selective predation plays a key role in determining community composition at different trophic levels (e.g. piscivore, planktivore, herbivore, phytoplankton and nutrient levels) (Kitchell and Carpenter 1993a). Piscivores affect the size and species composition of planktivore populations, which in turn affects zooplankton community structure and ultimately the phytoplankton communities that compete for nutrients (Figure 1).

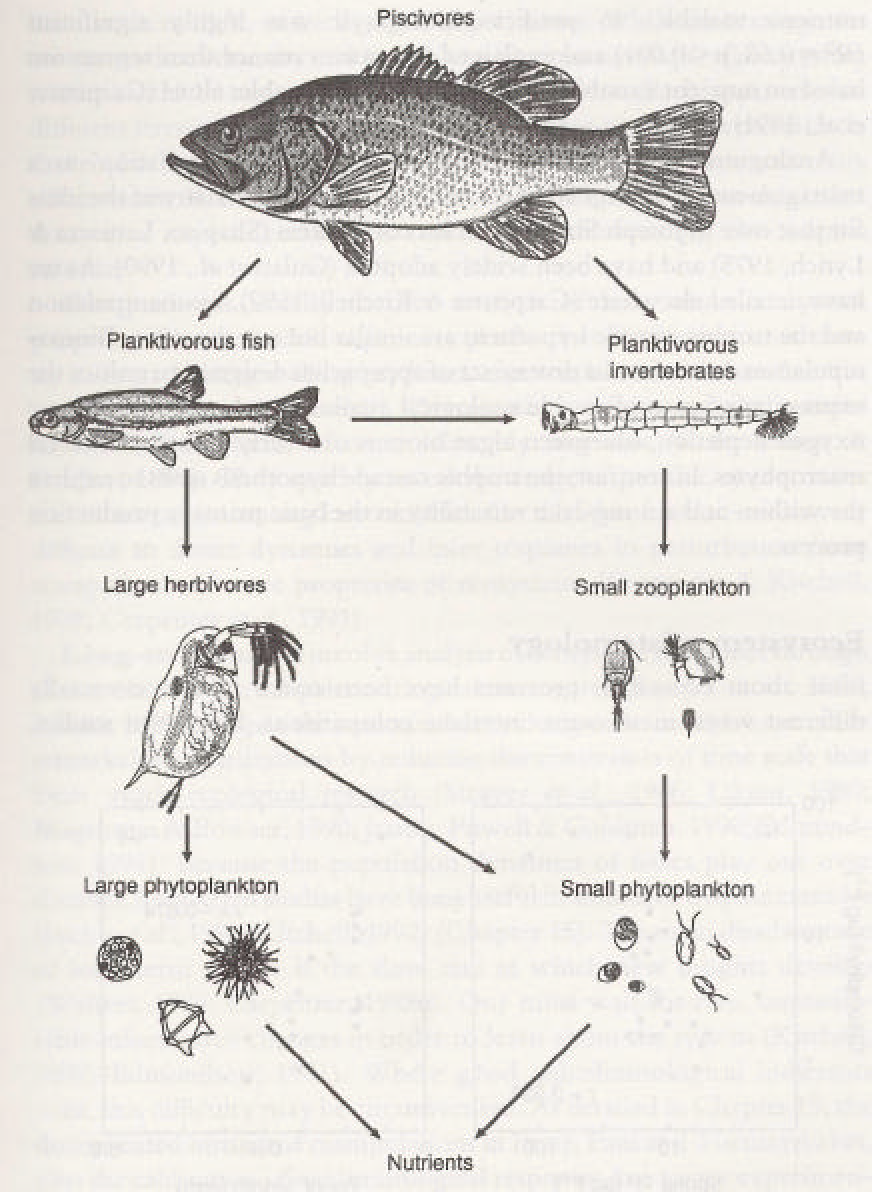

Figure 1: Major interactions of the trophic cascade (from Kitchell and Carpenter 1993)

Work in Lakes Peter and Paul began with mesocosm experiments that were soon overtaken by confounding factors. For example, planktivores such as minnows were placed in mesocosms located *in situ* to observe their effect on zooplankton size and species composition. However, the minnows took shelter when predatory largemouth bass approached the mesocosms; this effectively removed the size-selection predation effect of the minnows. The mesocosm experiments did not work but important lessons were learnt. It was decided that mesocosm experiments were pitched at the wrong scale and that whole-lake manipulations were required. During subsequent whole-lake experiments, it was found that planktivores sheltered in the littoral zone of the lakes when piscivores were present. The presence of piscivores effectively stopped the predation on zooplankton even though planktivorous fish were present in the lake. The decrease in planktivory resulted in an increase in cladoceran size, a decrease in algae resources and eventually a decrease in zooplankton biomass (Figure 2).

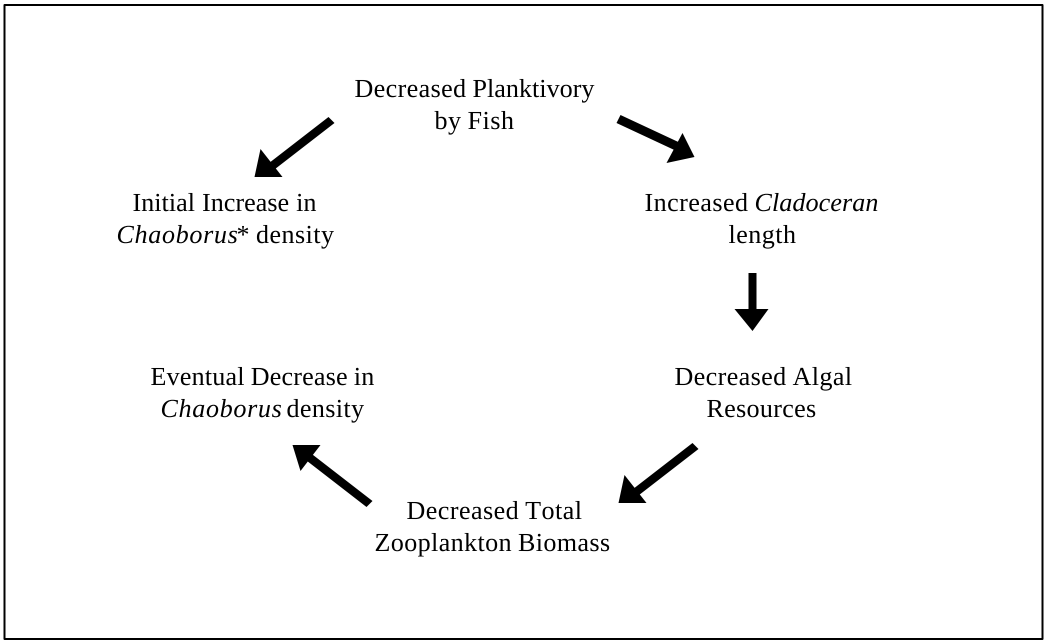

Figure 2: Effect of the introduction of Largemouth bass on zooplankton populations in Tuesday Lake (from Soranno *et al*. 1993). * *Chaoborus* is an invertebrate predator of small zooplankton.

2.2 Lake Mendota biomanipulation study

Lake Mendota, Wisconsin, has in the past carried the tag of the ‘most studied’ lake in the world. The lake had a history of noxious algal blooms in the decade leading up to the late 1980’s, and the initial management response was to reduce nutrient loading to the lake. While nutrient point sources were relatively easy to control, reductions in the nutrient load from non-point sources, such as runoff from agricultural land, were harder to achieve (Carpenter *et al.* in press). Achieving a continued improvement in lake water quality became quite a challenge and alternative management approaches, such as food web manipulation, gained increasing support.

The insights gained from the trophic cascade work were applied to Lake Mendota; by controlling predator-prey interactions it was hoped that the grazing of phytoplankton by zooplankton might be promoted. This period also coincided, in 1987, with a collapse in the stocks of the planktivorous lake herring or cisco (*Coregonus artedii*) and lower than normal nutrient loading to the lake (Kitchell 1992). The lake ecosystem therefore changed naturally from one of high planktivory to low planktivory, followed by a shift in zooplankton dominance from small to large species (*Daphnia* spp.) in subsequent years. The lake was restocked with piscivores in order to maintain pressures on planktivores such as cisco. However, as stocks of piscivores increased, so too did the angling catch rate (Table 1); anglers added another level of predation to the system.

While the results of the experimental manipulation did not go as planned because of the increased angling pressure, scientists and managers found that they could work together on such projects. It was felt that the insights gained from the manipulation were greater and occurred faster than would have been the case if a smaller, more cautious, approach was taken to experimentation.

Table 1: Summary of changes to angling catch rates in Lake Mendota, 1987-1989 (adapted from Kitchell 1992).

Angling Catch Rate (fish caught per angling hour)	1987	1988	1989
All piscivores	0.055	0.181	0.179
All planktivores	1.458	0.781	1.382

2.3 Lake Michigan

The construction of the Erie canal connecting the Great Lakes of North America with the Hudson River increased the opportunity for invasion by alien species of fish, such as sea lamprey and the herring alewife. The invasion of alien species, especially the sea lamprey, in Lake Michigan led to a decrease in native piscivore species, and a subsequent collapse in fisheries yields. Alewife populations flourished in the absence of a predator population, native planktivores declined due to intense competition and the alewife became the dominant planktivore in the lake. However, a density-dependent die off occurred in the mid 1960’s. As alewife began to recover, stocking rates of introduced Pacific salmon (*Oncorhyncus* spp.) increased to create a biological control of the nuisance alewife. By the 1980s, salmon abundance held the alewife at low abundance and the native planktivore species were recovering (Kitchell *et al.* 1988). The lake has since undergone dynamic changes to community composition and species abundance at different trophic levels due to strong interrelations in the food web and the invasion of yet more alien species such as the zebra mussel (*Dreissena polymorpha*). The dynamic nature of interactions between biota in the lake has led to some reassessment of initial conceptual models (Kitchell and Carpenter 1993b). For example, it was found that the predators stocked in the lake didn’t readily find alternative prey when the alewife declined to low levels (managers were wrong). However, there were general changes in the lake that were consistent with findings from other smaller lakes, such as Lakes Peter and Paul discussed in the previous section.

2.4 Pink Salmon stocks in the Pacific Ocean

Investigations of Pacific salmon stocks in the subarctic north Pacific Ocean undertaken by Shiomoto *et al.* (1997) indicated that between 1985 and 1994, phytoplankton biomass and Pink salmon abundance showed corresponding yearly patterns. Both the Pink salmon stocks and phytoplankton biomass increased in odd years (1987, 1989 etc.) and decreased in even years. Macrozooplankton biomass had an inverse pattern to that of Pink salmon and phytoplankton (zooplankton biomass was highest in even years), and was negatively correlated to Chlorophyll-a levels and Pink salmon catch per unit effort (CPUE).

As nutrient levels and year-on-year water temperature remained relatively constant over the 10-year study period, Shiomoto *et al.* (1997) considered that zooplankton grazing was responsible for the variability of phytoplankton biomass. Zooplankton biomass remained low in years when salmon stocks were abundant due to intense feeding. Prior to 1984, Pink salmon biomass was relatively constant at low levels and had little influence on zooplankton biomass. Pink salmon have a two-year life history and management increased the variability of fish stocks after 1985 (alternate years of relatively high and low abundance) (Figure 3). Feeding by Pink salmon reduced the biomass of zooplankton, and in turn resulted in increased phytoplankton biomass due to reduced grazing pressure.

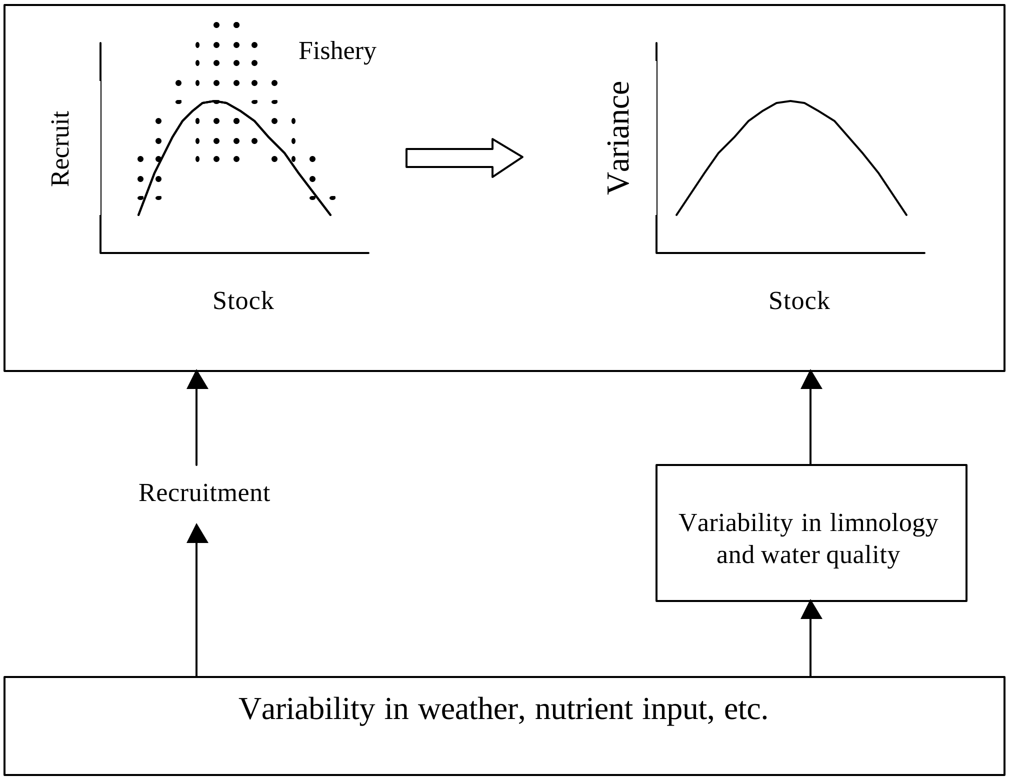

Figure 3: Variability in limnology and water quality derives from direct effects of weather, nutrient input, other physico-chemical variables, and from indirect effects of fish recruitment through the trophic cascade. Exploitation and management of fish stocks tend to sustain intermediate stock levels where recruitment, its variance, and variability in limnological variates and maximal. (from Kitchell and Carpenter 1993c)

2.5 General Discussion

It was proposed that the larger the scale of ecosystem manipulation the better, as more learning opportunities are likely to result. For example, assessments of how systems respond to drought and floods may help to define the scale of changes due to climate variability. Large-scale experiments require partnerships, which are accompanied by expectations and community involvement. Such partnerships may be difficult to forge and maintain. Undertaking a large-scale experiment may involve trade-offs. For example, a project based on high-powered hypotheses and statistical approaches will accommodate ideas accepted by scientific peers, but may prove to be of little use for assisting management decision making. Conversely, an experiment designed to achieve a management outcome may have little power to state whether changes, if any, are due to management actions. The factors that are required to sustain large-scale experiments are considered in more detail in Chapter 3.

While it is relatively easy for scientists to form partnerships with agency staff that generally have some technical background, it is much harder for scientists to develop partnerships with the wider community that does not have this technical background. One way around this may be a consensus-building approach to tackling issues. This may not make the immediate answers to a problem any easier but it will have spin-offs down the track in terms of promoting leadership and advocates for future management from within the community.

Internal tensions often exist in resource management agencies due to competing or conflicting demands. For example, an agency may have conservation aims or obligations while at the same time being responsible for restocking alien fish species favoured by anglers. Trade-offs may be required to resolve such tensions but the Lake Mendota experience showed that a lot could be learnt through cooperative efforts in such circumstances.

2.6 Lessons learnt from large-scale experiments

The lessons to have emerged from large-scale experiments so far suggest that:

- Ecosystems can be manipulated, sometimes with unforseen results. However, the opportunity for learning about how systems respond at large scales (the scale at which many management decisions are made) increases with the scale of the manipulation. Learning may be accelerated when resources are focussed on fewer, larger manipulations.
- There is evidence to support the value of learning by undertaking large-scale experiments and using analytical tools appropriate to that scale.
- If you cannot secure funding from traditional sources, then try to make powerful friends (especially managers) who may be willing to try alternative approaches.
- Partnerships may be difficult to forge and may not make immediate decision-making easier, but will lead to pay-offs in the future by establishing that scientists, managers and the wider community can work together to tackle big issues, and by promoting or developing leaders and advocates for change in the future.

3 EXPERIMENTS AT SCALES OF ECOSYSTEM MANAGEMENT

3.1 Context for ecosystem management

The growing field of environmental economics suggests that ecosystems should be considered within the wider economy, for example in terms of ecosystem services. A challenge for ecologists is to optimise the science that informs managers, so that they can maintain ecosystem services on behalf of the community. Improved decision-making requires better options and accurate predictions within a cycle of management action and evaluation (Figure 4). The role of science in resource management is to increase the set of useful options available to managers and increase the accuracy of predictions.

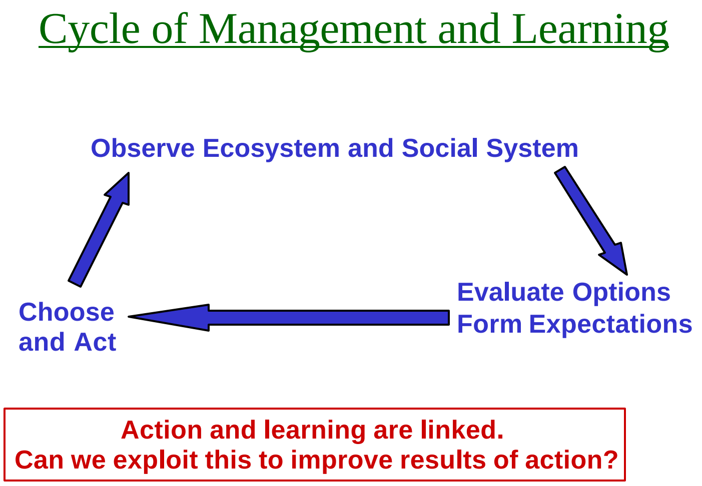

Figure 4: **Management and learning cycle (S. Carpenter, pers. comm.)**

Each component of an ecosystem (e.g. trophic level) has a characteristic spatial scale and turnover time (Figure 5). Keystone components, strong interactions and disturbance regimes create a few dominant scales at which ecosystem variance is large, and these provide cues that help us consider the drivers and equilibria that should be considered when trying to increase our predictive capability. For example, ecological research reduced the uncertainty associated with predicting eutrophication. Comparisons across a range of system types, long-term monitoring, and whole-lake experiments were important in this process. Whole-lake experiments accelerated learning by demonstrating impacts within a few years and showed that by manipulating P loads and the food web it was possible to affect chlorophyll levels (Hansson *et al*. 1998, Schindler 1977). Ecological research also enlarged the scope of decision options available to managers (do nothing; manipulate P input; manipulate food web; manipulate both).

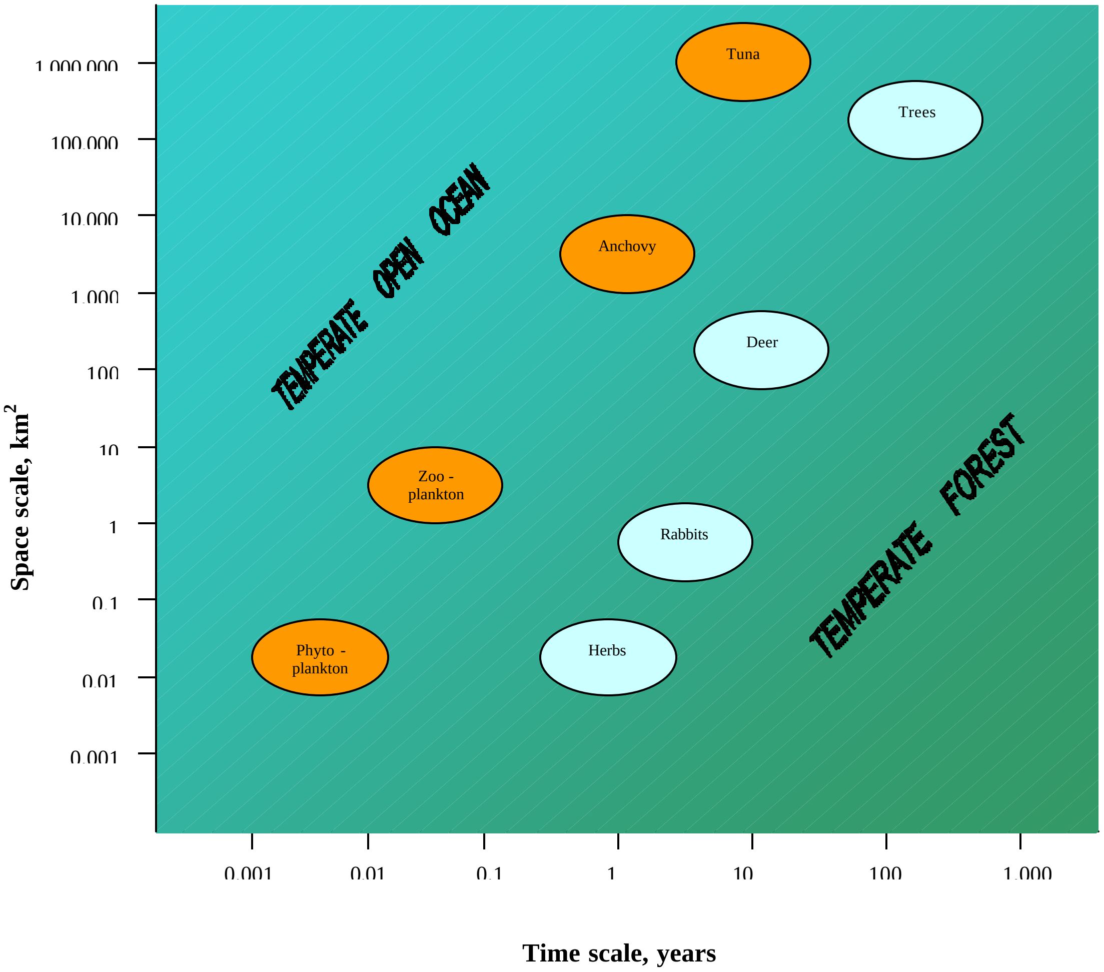

Figure 5: **Characteristic spatial and temporal scales for components of terrestrial and marine ecosystems (from Carpenter 1998).**

3.2 Characteristics of Successful Ecosystem Experiments

Successful large-scale experiments have five important attributes, including:

1. *The use of conceptual, graphical and mathematical models to find important contrasts*. Conceptual models and graphics help to define important concepts and interactions and also identify opportunities for management intervention or control. Conceptual models are also very important communication tools and can often be parameterised to allow some predictive capability.
2. *The use of all available information*. Using all the information available allows us to benefit from the experience of others (e.g. establishing prior probability), enables us to use insights gained from similar systems, and allows us to consider ecosystem drivers with large spatial extent or slow turnover rates.
3. *A simple design aimed at important contrasts*. Where possible, experimental design should be simple and targeted to examine important contrasts (e.g. drought or flood). The more complex the design, the harder it is to interpret and communicate results.
4. *A commitment to monitoring*. A commit to monitoring is required, as learning requires follow through. Important variables are always changing and a challenge is to devise

efficient indicators tailored to management questions. Many indicators prove less useful than originally envisaged.
5. *The use of visual aids, graphics, and comparisons of model fit*. Visual aids, graphics and comparisons of model fit are important communication and evaluation tools. We should continue to question which models fit the systems we wish to manage, which models are implausible and can be discarded, and what new models should be considered. The null model (hypothesis) that is the basis of many experimental designs is usually of little interest to managers, who are looking for new or alternative models for how systems work.

Progress in understanding large-scale ecosystems faces barriers, including:

- Intrinsic difficulties of large ecosystems (variability, multiple causality, slow dynamics);
- Academic culture (reward system focused on narrowly disciplined individual achievements and fast publication, which selects for ever more precise answers to the wrong questions);
- The culture of management (preference for command and control; the myth that current policies are knowledge-based answers; the belief that new information will threaten entrenched policy; the tension between careerism and the social mission of the agency; lack of institutional mechanisms that promote learning from experience);
- Institutional barriers (difficulty of sustaining creativity in large teams over long periods of time).

Changes that could accelerate progress in experimentation on large-scale ecosystems are:

- More attention to the role of leadership and its evolution, and the need to plan for succession of leadership;
- The need for dedicated sites with stable institutional arrangements;
- Stable core funding (which may be modest and augmented when necessary by grants aimed at specific questions).

3.3 General Discussion

Ecosystems contain elements that operate at both spatial and temporal scales. While spatial models provided useful information, for example identifying ecological gradients that may be present, they may be of little use for predicting how ecosystems might change over time (e.g. in response to disturbance). This emphasises the importance of collecting long-term data with which to assess ecosystem response to disturbance, including management interventions. This raises the question of what predictors or indicators should be used for modelling or assessment. Do we start with lots of predictors and drop those off as we realise they provide little or no additional insights? Are species good predictors (we collect a lot of data on species)? The trophic cascade work conducted in Lakes Peter, Paul and Tuesday (see Chapter 2) suggested that much of the species data collected provided little information, while information collected on crustacean body size proved to be very useful as it provided data with low variability and species level identifications were not necessary. Wherever possible, we should try to use predictors or indicators that are cheap and easy to measure.

Predictors based on zooplankton work in lakes, but what about in rivers? Rivers are open systems that are spatially heterogeneous. Physical drivers are more important in rivers than in lakes, which have drivers that are often non-linear. One place to start when establishing predictors of ecosystem response in rivers is with organisms that are adapted to flood and drought. This will help to identify the extremes of conditions to be encountered. IBI indices may also be useful but have a mixed review in the scientific literature, as they are sometimes promoted by individuals working on a favoured animal, rather than trying to develop an efficient tool for assessing ecosystem health.

The adoption of indicators has political and management implications; good indicators are those that have a clear link with components of systems that have to be managed. The aim should be for indicators that are relatively cheap, while still providing a lot of information (e.g. zooplankton body size as an indicator of fish and algae communities). Early warning indicators are also useful. For example, soil P has been used as a predictor of future lake P in Wisconsin. As soil P increases, lake P may be expected to increase in the future. This information can be used to develop zoning policy to manage soils. It is interesting to note a growing trend in the USA to pay landholders who provide waterway stewardship (e.g. for maintaining easements for wetlands). Such partnerships offer incentives that put landholders in a better position to manage land and waterways, and improve public confidence in restoration efforts.

4 LONG TERM MONITORING - NUTRIENT LOADING IN THE NEUSE RIVER

Nutrient loading in the Neuse River has been a big public issue in North Carolina, USA, over the past decade (Stow *et al*. 2001). The premise has been that eutrophication has decreased in the upper part of the Neuse River estuary, resulting in periodic large fish kills. However, there has been some controversy over the source of nutrients that are thought to support eutrophication and subsequent fish kills. The estuary has generally been regarded as nitrogen limited, though some evidence suggests limitation may be seasonal. The catchment has an urban population that has increased greatly over the last 20 years, with a concurrent increase in the volume of treated sewage discharged into the river. There are also numerous piggeries located across the catchment, and pig numbers increased from 2.6 to 8.3 million from 1989 to 1995. Most of the waste from these concentrated animal feeding operations is held in large lagoons and subsequently applied to agricultural fields. However, inefficient waste application and the failure of some treatment lagoons has led to a belief that much of this nutrient-rich waste is eventually entering the river and the estuary.

Sixteen water quality monitoring sites with more than 20 years of data have been established along the Neuse River and estuary. The long-term data were used to evaluate trends and examine seasonal variation in nutrient concentrations. Some of the relationships established from these data are: a negative correlation between flow and nutrient concentration, a drop in N and P concentration in the upper part of the watershed since the construction of a dam in 1983, and a drop in P concentrations since a 1988 ban on phosphate detergents. The 1988 P decrease is evident throughout the river and estuary. Increasing NO_3 concentration was responsible for an observed Total N increase in the upper part of the watershed, however this apparent increase is progressively dampened moving downstream and into the estuary. Over the same period TKN decreased slightly. This N pattern is consistent with the idea that, while discharges of treated sewage increased over this time period, the level of treatment received prior to discharge also increased, resulting in a greater release of oxidised N forms and a lesser release of reduced forms. The dampening of the N increase moving downstream suggests that some NO_3 may be lost to denitrification enroute.

A Bayesian probability network (Bayes net) model (Reckhow 1999) was developed to aid prediction (Figure 6). The nodes of the model use information from a variety of sources. For example, the frequency of hypoxia node uses site-specific information from the Neuse estuary (Borsuk *et al*. 2001a), while the Sediment O_2 demand node is actually Bayesian hierarchical model using data from many estuaries (Borsuk *et al*. 2001b). The Bayes net model is a “work in progress” and provides a framework that can be updated as more information becomes available.

Results of the monitoring and modelling of the Neuse River suggest that algae density is related to flow and nutrients, although it has hard to isolate the effect of the different nutrient forms present or their source. Adaptive management is required to reduce N loads and examine the response of algae to the variability of the parameters being monitored.

Summary

- Long term data are an essential investment for future management: to predict the future you need to understand the past.

- Statistics and modelling: data require interpretation, some parameters will require estimation. To providing useful information for management, we should aim for prediction, not just hypothesis testing.
- Graphical techniques are very useful as communication tools and are powerful for inference
- Adaptive management requires coordination between management and science to provide learning. Rigorous methods are required for updating and combining information. Testable hypotheses are also required.

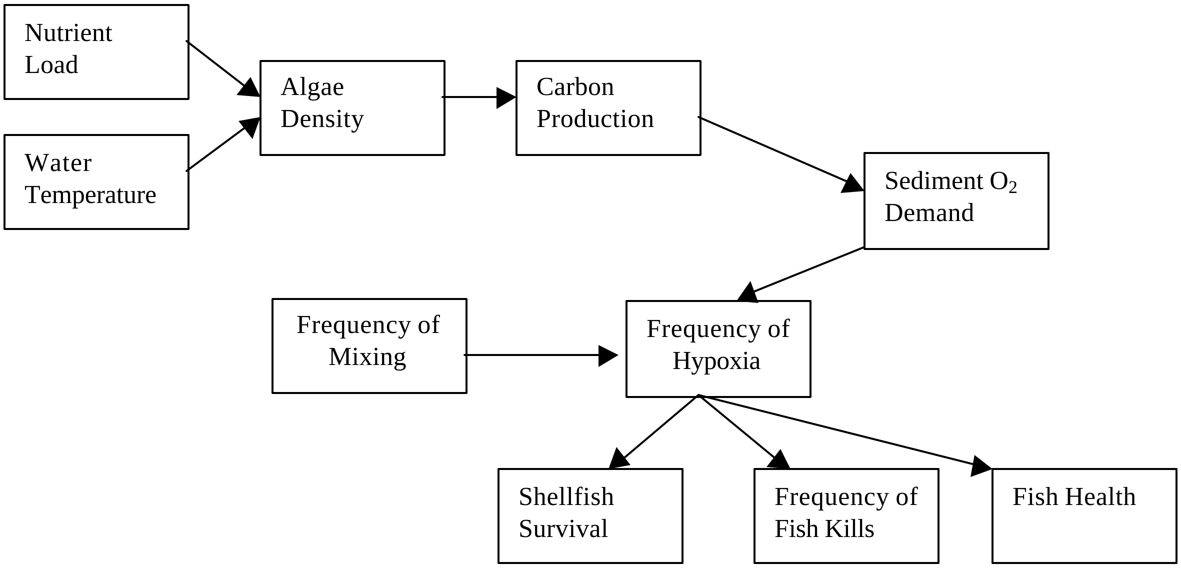

Figure 6: Conceptual model relating nutrient loading to hypoxia and fish deaths in the Neuse River (from C. Stow, pers. comm.)

4.1 General Discussion

The Bayesian approach is new to many researchers and managers in Australia, who are generally trained in parametric statistics. The major benefit in the Bayesian approach is its intuitive thinking. Works such as ‘The Ecological Detective’ (Hilborn and Mangel 1997) and ‘Making Decisions’ (Lindley 1971) are recommended as easy to read accounts of gaining insights from ecological data.

While development of the Bayesian model of the Neuse River continues, two additional eutrophication models are being developed by the state of North Carolina and the US EPA. These two models are mechanistically based and operate on finer spatial and temporal scales than the Bayes net. However, mechanistic models are generally calibrated to capture central tendencies, making it difficult to predict extreme events. The mechanistic detail of the two additional models also makes a full uncertainty analysis extremely difficult. While a criticism of the Bayes net model is that it is more aggregated in space and time, making it difficult to separate some of the specific processes occurring, a particular utility of the Bayes net is that it captures uncertainty probabilistically. Because it is probabilistically based, it can be used to estimate the likelihood of extreme events in a way that the mechanistic models cannot. Reducing the frequency of extreme events is often one of the goals of environmental management. Additional spatial or temporal detail could be added to the Bayes net, if sufficient information became available to support the added precision.

It is often difficult to get or maintain a commitment to the collection of long-term data, as the relevance of the data may not be apparent to funding bodies in the short term. Long-term data should be seen as an investment for the future management of our ecosystems. However, it should also be recognised that new data may not be immediately useful. Data paid for by public funds in the US and Australia are free to users. But data are not often contained in databases that are easy to access and use. This adds to the frustration of those who wish to use the data and may also add to the perception that a lot of data is collected unnecessarily (at great expense) as it is never used.

Adaptive management implies that managers must be prepared to make mistakes, as must scientists. Some of the best learning experiences emerge from outcomes that were unexpected. While managers and scientists may accept this, we should recognise that this is a message some will not want to hear.

5 ADAPTIVE MANAGEMENT

Adaptive management is 'learning by doing' (Figure 7). It is best advanced by using all available information and requires monitoring so that we may re-evaluate what we know, form new conceptual models and make new decisions. We all do adaptive management, all of the time; however, sometimes we do it poorly as we do not monitor or evaluate the results. For example, approximately 80% of the decisions made by Canadian Fisheries are not evaluated (Hilborn, pers. comm.).

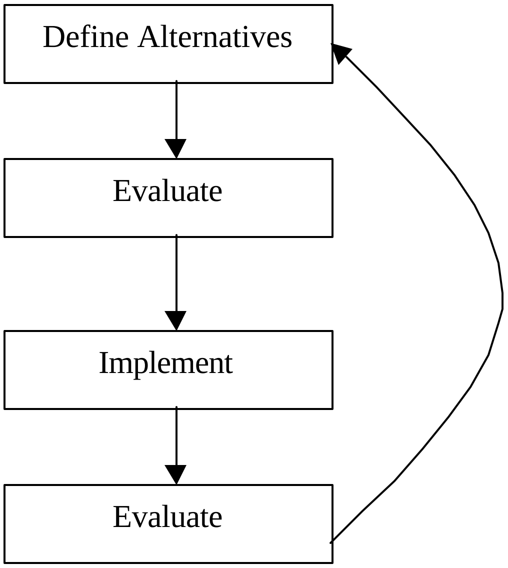

Figure 7: The adaptive management cycle (from Hilborn, pers. comm.)

Key tenets of adaptive management include:

- At any time our knowledge consists of what we have learned from the system of concern and what we have learned from other systems;
- Management is a decision-making process based on best available information;
- Rarely do we achieve the level of certainty associated with $p<0.05$ – uncertainty is pervasive.

From adaptive management we can learn that:

- Uncertainty decreases with monitoring;
- No monitoring often means no learning;
- Large perturbations are more informative than small perturbations;
- Managers must trade off the cost of large-scale experiments against the learning they provide.

Scale and replication:

- Whole system scale gives the most relevant data for managers;
- We learn faster if spatial replication and controls are available, but we can still learn without them (Figure 8), although at a slower rate and without the level of certainty that controls and replicates afford.

Systems change over time, so we need to continually monitor and evaluate our understanding. Over time, definitive experiments lose their relevance.

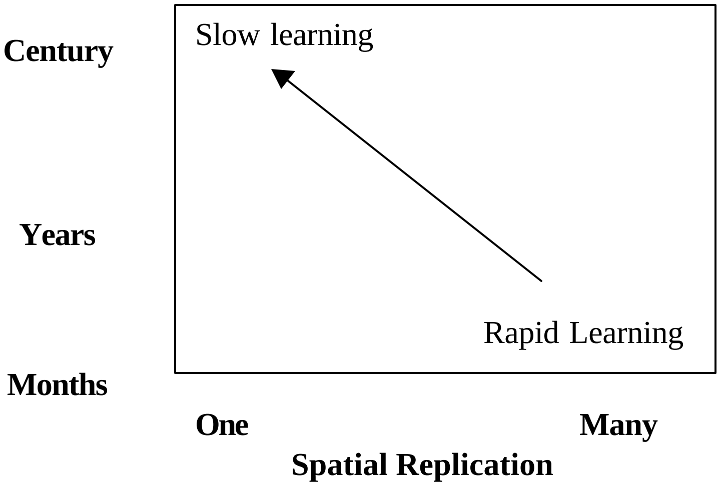

Figure 8: Spatial and temporal scales of learning

5.1 Statistics and Adaptive Management

As managers we want to know the credibility of competing hypotheses. P-values become irrelevant, as we may be interested in many hypotheses, not just the null hypothesis. It may therefore be useful to:

- Forget:
  - Null hypothesis;
  - P values;
  - 1 or 2 tailed tests;
  - All you know is what you learnt in the experiment.

- Remember:
  - Probability;
  - Experimental design;
  - Common sense;
  - What you know after data collection is what you knew before, modified by what the data taught.

The contest between data and a single hypothesis applied at small scales makes little sense to managers, who are more interested in the contest between 2 or more hypotheses, usually at large scales (Figure 9). Insights may be gained from an example that considers freshwater fish survival in response to changes to flow (Figure 10). It may be hard to detect an effect with relatively small changes in flow. The probability of detecting an effect increases with bigger flow manipulations and longer data sets. Strong and sustained manipulations through management actions can reveal both the appropriate scales and the complexity of responses that will assist learning through deliberately planned adaptive management.

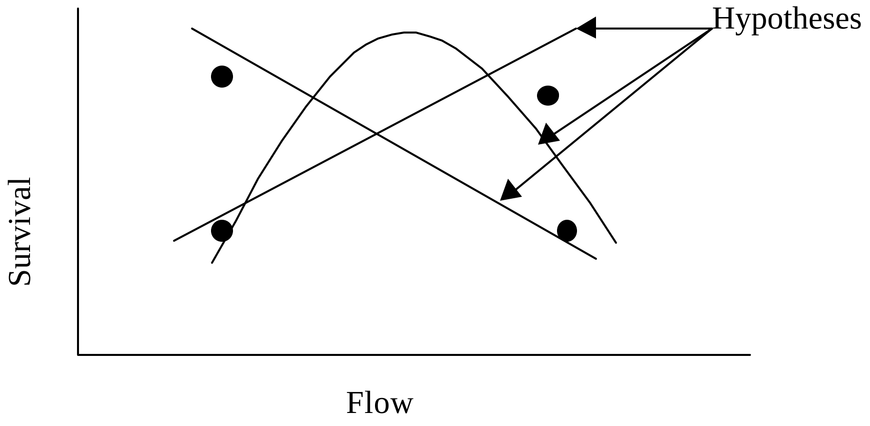

Figure 9: **Potential flow-survival hypotheses to explain observed data**

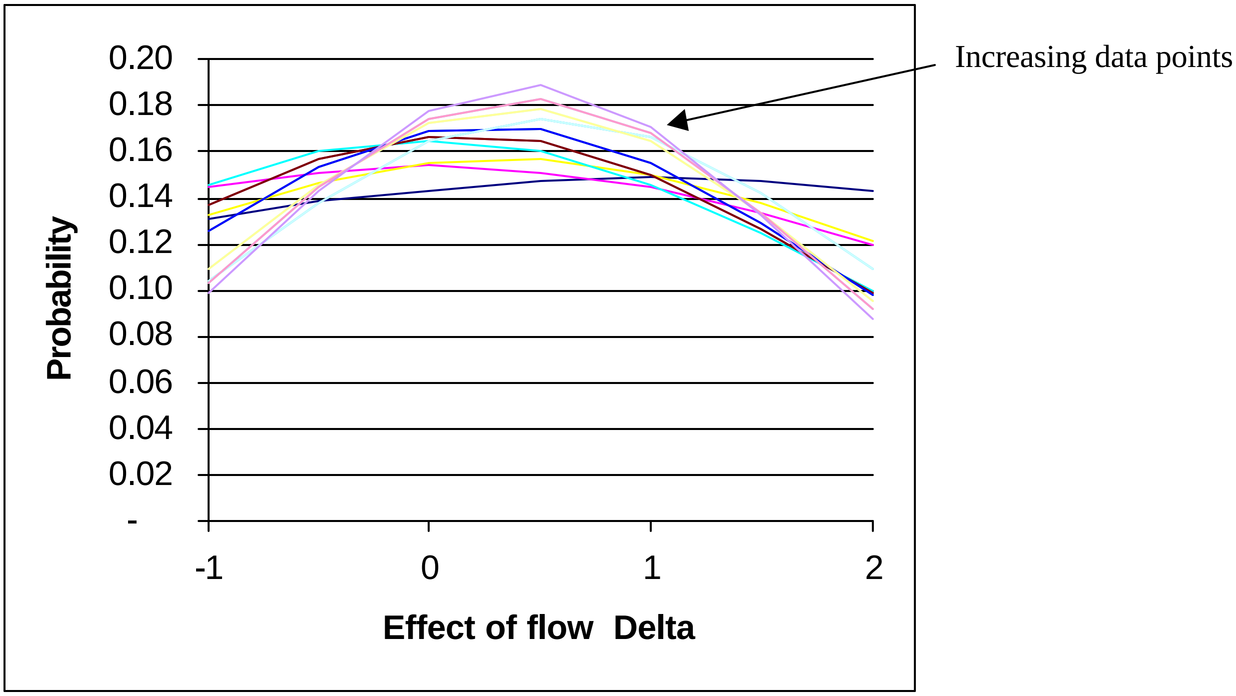

Figure 10: **Example of increased probability of detecting changes to fish survival in response to flow manipulation (from R. Hilborn, pers. comm.)**

5.2 General Discussion

In Australia we are often confronted with trying to detect relatively small effects in naturally variable systems (e.g. diversion of 10% of stream flow). One approach is to use modelling to look at likely signals of ecosystem response. 'Before' data will be valuable for helping to detect action effects, while considering the extremes of variability (e.g. drought, flood) will help set the bounds of the exercise. Information from other systems may also be useful (e.g. Meta analysis).

Examination of P-values (mechanistic approach) removes bias from the results of experimentation. Adaptive management based on assigning prior probability (Bayesian approach) runs an increased risk of bias in decision making, or a tendency to make too many decisions or react too quickly. Decision rules in the feedback loop of adaptive management should overcome this problem. A management decision log would also be useful to state how a decision was made and when it should be evaluated (a good idea that is rarely practiced). Often there is no end to adaptive management, although irreversible decisions may be made. Continued monitoring and evaluation is important to inform the adaptive management process in the future.

While Bayesian predicability can be useful for informing management, trying to unravel causality via the mechanistic approach will still have benefits. A mechanistic approach can help to identify good management approaches even though it cannot be used to predict the future. Scientists will still want to confirm the underlying basis for change in response to actions (i.e. understand what makes things tick).

It is often difficult to instil a culture of adaptive management in resource management agencies, as managers who must also juggle socio-economic issues generally prefer stability in the outcomes of decision making. However, stability generally provides few learning opportunities. Adaptive management has been adopted at policy level in the USA, but has had little effect in practice. The current situation is that there is adaptive management of sorts, but it is slower and less efficient than it could be. Adaptive management could be improved if more decisions were monitored and evaluated, something that often gets ignored. Adaptive management breaks down if we cannot convince others of the importance of monitoring and evaluating decisions, and feeding the lessons learnt back into the decision making process. This is where a large-scale project really helps.

6 OPEN FORUM

The Open Forum provided an opportunity for those at the workshop to discuss various aspects of ecosystem management and share their experiences. The following sections provide an overview of the issues discussed.

6.1 Adaptive management revisited

Adaptive management is a great learning process if done well. However, adaptive management doesn't mean that decisions remain fixed. On the contrary, it means that policies are recognised to be hypotheses masquerading as answers. Management actions are viewed as an opportunity to learn and thereby create better policies in the future. This requires a partnership of management, research and monitoring to create the knowledge needed for steady improvement of management.

There has been considerable change in the Australian water industry over the past decade. The water industry was once dominated by skilled engineers, but industry rationalisation was accompanied by widespread deskilling and resulted in agencies being run by business managers. Restructured agencies have come to rely on consultants from whom they outsource knowledge about the systems they manage. It is now recognised that the purchaser-provider model for supplying ecological information to the water industry in Australia is flawed. A similar separation of agencies and science in the US has had mixed success, as policy groups found they still required scientific advice to make decisions. There is now growing support for a new kind of environment professional, for example an expert practitioner who helps facilitate the interaction between decision-making and action (Cullen 2001).

In Australia we often deal with the issue of 'what is a sustainable environment?' Water resource managers tend to take a cautious attitude to defining sustainability, as the political fallout of failure may be great. In such circumstances, it is often difficult to resolve ecological issues in the absence of an ecological crisis. Crisis galvanises people into action and in many circumstances there will be no resolution to an ecological issue until a crisis occurs. Industries such as agriculture can quickly point to crises (e.g. crops decimated due to drought or flood) as the effects are generally felt personally by their constituents (i.e. farmers). However, the effects of ecological crises on the community may be slow to emerge, or may be ignored until they have some socio-economic impact. Stakeholders may not realise they are involved until there is a an ecological crisis and experience has shown that there is often a certain amount of 'posturing' or 'finger-pointing' before disparate groups work cooperatively. The communities of catchments with a history of crises are generally better organised to respond to new crises.

6.2 Models, monitoring and evaluation – essential tools for managing variable systems

We still grapple with how variable an ecosystem might be and how much control we might have over it. It has been argued that most of our management effort is placed where systems have the highest variability and therefore lowest predicability (Figure 11). The greatest opportunity for learning occurs when management responses to an issue are strong. As scientists and managers we should be ready to take the opportunity to conduct large scale experiments as they arise ('chance favours the prepared mind – and budget' – J. Kitchell, pers. comm.). Our current experimentation and management tends to focus at the lower to mid range of the learning curve presented in Figure 11.

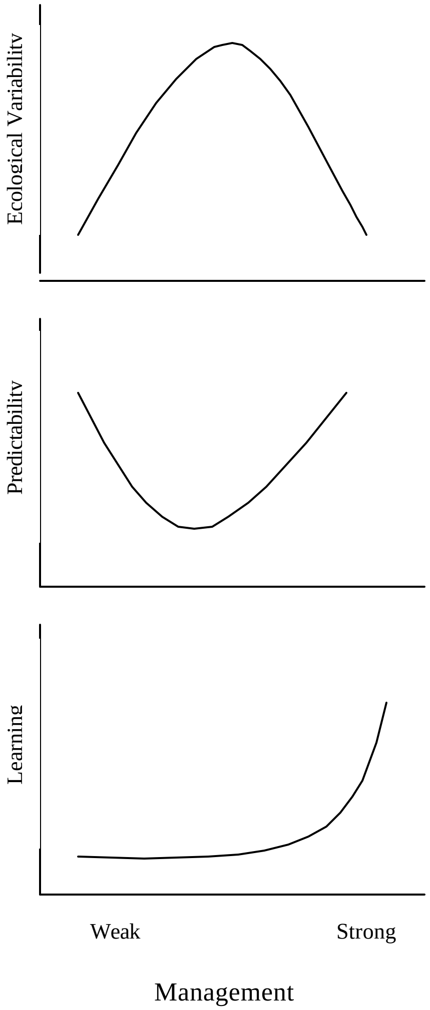

Figure 11: **Hypothesised relationship between ecological variability, predicability and learning (from J. Kitchell, pers. comm.)**

Different people will have different expectations of management and it may be difficult to ensure that expectations remain realistic and so avoid disappointment. Conceptual models are very useful tools as they help to develop plausible visions for the future that may be shared by stakeholders. Conceptual models may be particularly useful when dealing with zealots, who may have an inflexible attitude to an issue. Unfortunately, conceptual models are tools in which we generally under-invest. Also, there are relatively few ecological modellers in Australia.

Different approaches to modelling are promoted by the scientific and engineering community and it is difficult for a manager to judge the relative credibility of models promoted by different organisations. Two types of model should be considered:

1. Models for understanding (e.g. pictures, graphics). These are good for communicating ideas and developing a common understanding of an issue. They may be parameterised to some extent to provide some level of prediction.
2. Technical models that are very detailed and precise, and that are designed to address a narrowly defined issue (e.g. 2-D and 3-D water quality models). Such models may provide a good level of prediction but may have limited use for building understanding.

Models allow us to make predictions about the response of ecosystems to disturbance. There will always be uncertainty associated with such predictions, something that should be stated clearly when applying models. Disagreement among stakeholders about which model is best suited to an issue may indicate the presence of another agenda and some form of comparison may be required to resolve the issue. For example, US detergent companies insisted that organic compounds were responsible for eutrophication. Lake experimentation showed P limitation and led to a ban on P in detergents (Schindler 1977).

The collection of long-term data should be seen as an investment for future decision-making. Data collection should be designed to account for the natural variability of the system being monitored, for example climate variability. If the long-term data does not capture the variability of the system then it is of little use. For example, 15 years of water quality data were ignored during investigation of nutrient loading to the Neuse River (C. Stow, pers. comm.).

The success of management decisions is rarely evaluated formerly. This may occur for many reasons (lack of resources, fear of recriminations) but usually represents a missed opportunity for learning. Recent reviews (Walters 1998) suggest that a lack of evaluation has led to the perception that adaptive management has failed as a process, as people have learned little from the management experiments conducted so far. The collection of long-term data is very important as it will aid future evaluation of management actions. The availability of data is also important as it allows alternative analysis of results.

6.3 Where is ecology going?

Research is often thought of in terms of whether it is basic or applied. Another way of looking at research is whether it proves useful for resource management decision making, or not. Often, the usefulness of research is not clear until it is complete. Rather than placing all available resources into one form of research, it may be better to consider a ‘portfolio’ that in addition to applied research, includes:

- Research into efficient and informative indicators of the status of a system;
- Research on how to make management more adaptive and how to generate a culture of taking on new ideas;
- Blue-sky research.

New insights that will be of particular use to water resource managers are likely to be gained from considering:

- Population dynamics in heterogeneous systems;
- The use of remote sensing for natural resource evaluation;
- Ecological economics and increased interest in having ecology included in decision making processes (e.g. definition of ecosystem services and assigning a market value to ecological processes);
- The large scale links between biodiversity and ecosystem function;
- How to realise new solutions to environmental problems (e.g. development of future visions for the environment).

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