Conservation of coastal organisms depends on scientific realism, not community "monitoring"

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ABSTRACT

By signing the Rio Convention on environment and sustainable development, Australia has made a long-term commitment to the conservation of our unique flora and fauna. This includes the diverse, but often ignored small animals and plants living on and adjacent to our coasts. Many of these animals and plants have "broadcast" fertilization, dispersive larvae and very variable survival in the plankton. Patchy patterns of arrival of new animals into coastal habitats, along with varied interactions among species and between organisms and their surrounding environment, lead to characteristic patterns of coastal biodiversity. This biodiversity is patchy from place to place and variable from time to time in interactive and unpredictable ways. Conserving this biodiversity depends on throwing away old-fashioned, irrelevant ideas (such as the balance of nature) and recognising ecological realism. Community "monitoring" is becoming an important component of conservation in many parts of Australia. There has, however, been little serious thought about what data are collected in "monitoring" programmes, what they might mean or what they might be used for. Ecological data collected without clear hypotheses are generally pointless, or cannot be used for the purpose intended. Data required to measure biodiversity, or changes to biodiversity in such complex, variable systems as coastal habitats, cannot be collected and interpreted without considerable knowledge and expertise of sampling design, ecological theory and modern analytical methodologies. This means that they cannot usually be collected by amateurs or scientists not trained in and practising this type of ecology. It is sometimes suggested that ecological "indicators" be monitored as a means of simplifying the types of data collected, but it is seldom clear what it is that most indicators are supposed to indicate. Conservation of coastal habitats is not likely to progress by handing over measurement of their well-being or potential degradation to those ill-equipped to make such measurements. There are well-documented examples of the collection of useless data by non-trained observers, when the data being collected were much simpler than those needed to inform about coastal habitats. What is needed is a proper partnership between the community, who have a primary voice in what level of conservation is needed and what should form the priorities and the scientists, whose expertise and skills are needed to ensure that conservation is, indeed, occurring. These different roles are not interchangeable. Confusion between them will be to the continued detriment of our unique coastal habitats.

Introduction

The so-called Rio Convention on environment and sustainable development (World Commission on Environment and Development 1987) has caused major changes in the mix of social aspirations, political manoeuvring, bureaucratic jostling and scientific contributions in Australia's environmental management. Because Australia has signed the convention, it is important to be clear about the consequences for our (internal) long-term wishes to conserve our unique flora and fauna. We must also be very clear about our external, long-term international commitments.

Pp 20 - 37 in *A clash of paradigms: Community and research-based conservation*, edited by Daniel Lunney, Chris Dickman and Shelley Burgin 2002. Royal Zoological Society of New South Wales, Mosman.

This paper describes several aspects of needs for conservation of coastal marine fauna and flora. This choice of focus is because we (the authors) have long-term skills, expertise and experience in the ecology of the biota and the habitats. We clearly have some knowledge of what needs to be done. We also have had realistic involvement in projects involving Federal, State, Local governmental agencies and community groups. This provides some knowledge about what is being done in contrast to what needs to be done.

The paper briefly summarises known ecological principles about coastal habitats and assemblages. It then considers what are the purposes of the increasingly popular notions about monitoring programmes in relation to coastal biota. The problems of the latter as incompetent science or non-science are illustrated.

The next theme is the vast, misunderstood structure of indicators of environmental change and what they cannot be used for. What properties indicators must have are briefly reviewed and needs for sound ecological information made explicit.

Then, the nature of appropriate measures of changes in biodiversity are described, with an introduction to the complex mixture of logics and statistical procedures necessary to analyse and interpret information.

Finally, we illustrate well-documented examples of why surveys and monitoring done by unskilled and undertrained amateurs cause so many problems that they divert energy and effort from more useful and much more efficient ways of getting reliable information about coastal biodiversity.

The paper concludes with a recommended way forward to achieve a more useful partnership between the aspirations of community groups and the work of competent, quantitative and analytical ecologists. Such a partnership would be better able to review and improve the roles of agencies and bureaucracies (a pressing need in any democracy). It would also greatly increase the acquisition, dissemination and use of proper information about problems for and management of coastal biodiversity.

Biodiversity in coastal habitats is varied, patchy, complex and interactive

In 1998, after decades of structured experimental ecological research on the coast-lines of southeastern Australia, it is time everyone accepted documented facts about the ecology of coastal organisms. Little needs to be presented here because of the wealth of information available. It is not satisfactory for self-proclaimed experts not to have acquainted themselves with the available information. The relevant features of coastal ecology are:

- many animals (including local species, e.g. Anderson 1960) and plants have "broadcast" reproduction; they shed eggs and sperm or larval stages into the water, which, during development of planktonic larvae, carries them up and down the coast (Mileikovsky 1971; Scheltema 1971; Thorson 1950);
- during these stages of life, there is usually very great mortality, so that relatively few larvae survive to settle into an appropriate habitat (Thorson 1950; Underwood and Fairweather 1989). Mortality is often due to predation, sometimes to starvation and can be because larvae are carried away from the coast and are lost away from their necessary habitats;
- the results of these processes are that numbers arriving in any area of habitat are variable from year to year and area to area (for coastal habitats in New South Wales, see Underwood 1999, Underwood and Denley 1984). If conditions in the plankton happen to favour faster development (so that larvae need to spend less time there) and/or decrease the numbers or effectiveness of predators, there will be large numbers of larvae arriving to settle in some areas (see Suchanek 1985; Underwood and Fairweather 1989, for examples). Numbers of animals and plants will therefore vary from time to time and place to place (Figs 1 and 2);
- while all this is going on, there are complex processes and interactions among species in the habitats where larvae will settle. There is competition for space (e.g. Connell 1961) or food (e.g. Underwood 1978, 1984), pre-emption of space, i.e. one species occupies the habitat so other species cannot settle (e.g. Jernakoff 1985a; Underwood and Denley 1984), grazing (Underwood 1980), predation (Fairweather 1988; Paine 1974), disturbances from storms

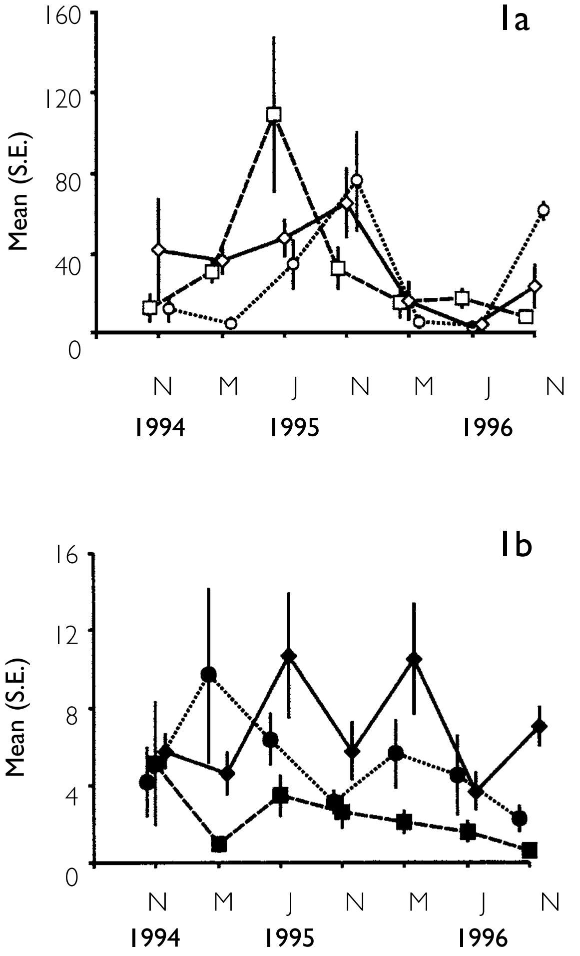

Figure 1. The abundances of animals are not constant and vary differently at different spatial scales and from place to place. Data are mean abundances (± Standard Errors) (a) of the snail (*Turbo undulatus*) in three sites (10s of metres apart) on the rocky shore at Little Head (Sydney); (b) of the whelk (*Thais orbita)* on three shores (several kilometres apart) in northern Sydney.

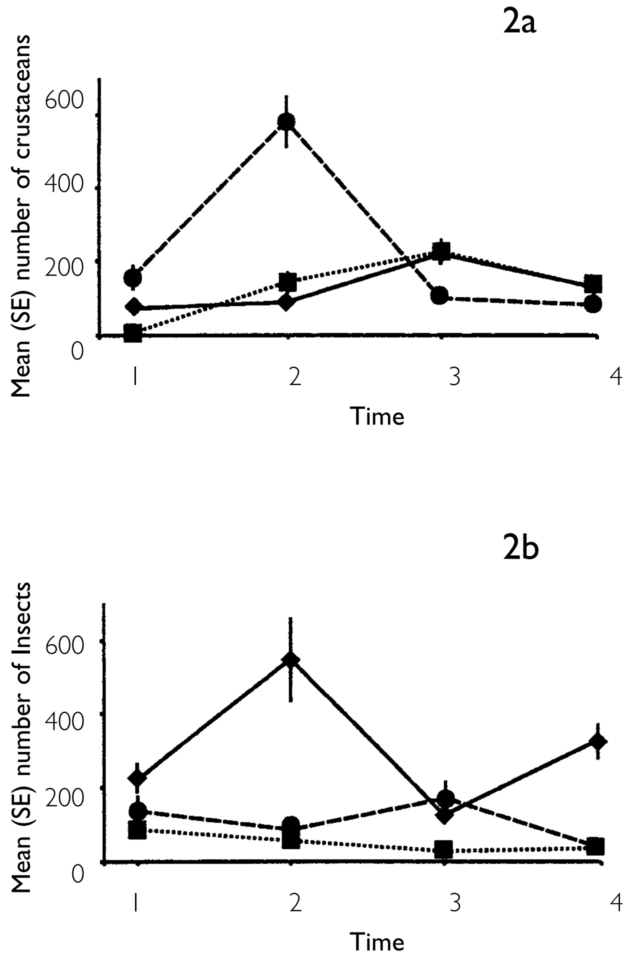

Figure 2. Mean numbers of animals in mangrove forests vary in different ways from time to time and place to place. Data are mean abundances (± Standard Errors) (a) of crustaceans; (b) of insect larvae in three sites (10s of metres apart) in mangrove forests at Homebush Bay, Sydney.

(Dayton 1971, Underwood 1998a), patterns of movement into and out of areas (Chapman and Underwood 1994). Finally, some species provide habitat for other animals and plants (Jernakoff 1985b; Mapstone et al. 1984). All of these are *interactive*, so that predation influences competition, competition influences behaviour and recruitment, etc. (summarized in Underwood 1985, Underwood and Denley 1984).

These sorts of interactions among the species in assemblages on intertidal rocky shores were reviewed by Underwood (1985, 1994) and Underwood and Chapman (1995). Similarly complex interactions are found in kelp-beds (Kennelly 1989), seagrass beds (Bell and Westoby 1987) and mangrove forests (Underwood and Barrett 1990).

As a result, there are changes from time to time in the mix of species present, in their relative abundances or cover of the substratum and in their sizes. The patterns in any one place are quite likely to be different from those somewhere else. Because the different numbers and mix of species in two places will interact differently, the changes through time will not be the same from one place to another.

So, the known, documented, experimentally analysed and properly described and interpreted ecology of coastal species demonstrates that there are no equilibria or constant abundances (Simberloff 1980; Underwood 1989) and no evidence for any so-called "balance of nature" (see particularly Andrewartha and Birch 1954; Botkin 1990).

Such complexity in numbers and types of animals and plants, varying from place to place and time to time, but differently from place to place *is* the biological diversity of our coast. Measuring biodiversity, documenting how it changes up and down the coast and determining how it varies and changes through time are the tasks needed. These are, however, difficult and technically complex tasks.

What might "monitoring" mean?

Environmental monitoring is usually defined as the process of gathering routine information, often in fixed locations at fixed intervals of time on the premise that this will be useful for detecting environmental change. Community monitoring is the use of unskilled or untrained members of the public to take the measurements, but such programmes often have grander aims. For example, it is claimed with respect to community monitoring in catchments that "community participation enables better understanding of the functioning of the catchment" (Keith and Foster 1996). It is almost impossible to comprehend how this statement could have any meaning. Understanding the function (however that might be defined) requires understanding of the processes that operate within a catchment. These are not understandable from any exercise in monitoring - they require interpretation of the outcome of experimental tests of specific hypotheses derived from models about functional processes in a catchment. Sometimes community involvement is stated to be in "action or participatory research" (Kelly 1995). This is apparently based on some ill-defined premise that the community has "the authority to define and analyse the research task". This rather supposes that no-one with any professional skills might have greater authority to do so. This dangerous notion goes on to claim that "community research will be based on action and commitment rather than detachment and objectivity" (Kelly 1995). It is mandatory that findings of research will actually be objective and not emotional and purely in response to commitment. This sort of argument presumes that action is entirely equivalent to progress.

Almost invariably, "monitoring" is a simple-minded, pseudo- or quasi-scientific way of spending money to accumulate uninterpretable information. This harsh view has been documented elsewhere by numerous authors (see reviews by Underwood 1989, 1991a). The problems are many and can be summarized as follow.

(1) Hypothesis-free data-gathering is not progressive

The acquisition of data - any type of information - without any logical structure in which to interpret the information is, almost without exception, pointless (Green 1979; Simberloff 1980; Underwood 1990). For example, data on water quality are increasingly collected, by all sorts of people, in the belief that measurements of certain physical (e.g. turbidity) or chemical (e.g. concentration of nitrates) variables will tell us whether or not a body of water can be considered satisfactory for sustaining biological diversity. Not only is this largely ill-conceived on the basis of known facts (see later), it is ill-conceived as a routine measurement. There are no definitions of what sort of values (of turbidity or nitrate) that would be appropriate to "sustain" diversity. There is no definition of what sort of change in these variables would identify a problem. There is nothing to guide how often or how precisely the measurements should be taken. Monitoring (i.e. routinely measuring) physical or chemical variables would be a useful exercise only where the information obtained is explicitly what is needed to test hypotheses about environmental change and to use the results for managerial decisions.

If these things were known, it would no longer be necessary to keep "monitoring". It would be cheaper, more efficient *and* more useful to design the appropriate sampling in order to detect reliably the sorts of changes that would matter (Green 1979).

A much more coherent and scientifically sound manner of proceeding in programmes about environmental change would be to do some real science. This proceeds from observations (things we know about the world before any monitoring programme is designed) to models or theories (explanations of *why* the world is as we observe it) to predictions or hypotheses (statements about what will happen under different circumstances if our model of the world were correct). Data - the measurements to be made - must then be collected in such a way that we can determine whether or not our model is realistic. If it is, we can continue to use it. If it is not, we *must* abandon it and seek a new, better one.

This logical framework is well understood in science (Popper 1968; Shrader-Frechette and McCoy 1990; Underwood 1990). It is also widely and successfully used in coastal ecology (Underwood 1991b) and environmental management (Underwood 1995, 1998). Further, such a framework focusses attention on what to measure, where and when and how to measure it and how to interpret any measurements that are made.

(2) Variable and complex ecology requires careful and skilful experimental and sampling design

The above conceptual framework just summarized recognises that things being measured are usually complicated and variable. Only when there are explicit models and hypotheses is it possible to design a programme of measurement that can produce reliable measures.

Because coastal ecology is intrinsically patchy and variable, it is not possible to make useful measurements without great attention to the problems of sampling. To be useful, measurements must be accurate and precise. These are technical terms which mean very different things, even though there is widespread confusion in the public use of the words. Getting *accurate* measurements requires great care in how to get the measurements. They must be representative of the system being measured, so the sampling must be designed carefully to ensure that measures *are* representative. Sampling will always be necessary because, for example, not all of the water in an estuary can be measured, only the bits we can afford. It takes an enormous amount of training and experience to be able to take representative samples (e.g. Green 1979). It takes skill with the equipment being used (although that is often simpler). It is, however, absolutely the case that accurate measures are absolutely impossible if the variables to be measured are not defined and the times and places to measure them (the "domain" of sampling or the population of measures) are not identifiable. Both requirements are only possible if the hypotheses are clear.

To get *precise* measurements is much more difficult. This requires estimating the intrinsic variability in the data and then using various techniques in experimental design (such as stratified sampling, optimal cost-benefit procedures, transformations of data) to produce the least variable average measures (Green 1979; Underwood 1997a). This is a particularly difficult, technically complicated topic. What drives the design of a study to ensure it is precise is the need to define how precise a measurement must be. Without clear hypotheses and therefore very clear understanding of how to use or interpret a measurement, it is impossible to define how precisely the measurement should be made. Where measurements are not precise, they are useless.

Consider a proposal to build houses in one quarter of a wetland that is habitat for wading birds. Opponents may argue that there are only 2,000 birds and loss of 500 would be disastrous and could drive the species to local extinction, because 1,500 is too few. The developers may argue that there are 4,000 birds. Even if there are only 3,000 afterwards, that is sustainable because it is much greater than the critical 1,500. A commission of inquiry discovers that the available measure from the opponents is 2,000 birds, with error or imprecision, measured as confidence limits ± 1,200. The developer, however, estimates that there are 4,000 birds ± 1,500 (CL). What is clear is that the two measures are not actually different (the real number could be between 800 and 5,500 which are consistent with both sides' data). Obviously, the measurement is too imprecise to use to determine how many birds there are!

Without hypotheses, measurements can be neither accurate nor precise. Unless as accurate as possible and as precise as necessary, measures are not worth making.

(3) Most monitoring violates precautionary principles

Apart from the above considerations, there are severe problems for routine monitoring (i.e. collecting data in some regular time-course not defined specifically with respect to the hypothesis for which the data are being collected) in any attempt to conform to principles of ecological sustainability. The guiding principle is the use of precaution. Precautionary principles mean different things to different people (Fairweather 1993; Gray 1990), but have specific meaning in environmental measurements (Underwood 1997b). Whatever measurements are made to test any hypothesis (to determine if it seems true), two types of mistakes are possible. For example, suppose it is proposed to open up an area of coast to a new type of fishing involving chemicals to stun fish. The proposers and regulatory body may say that such fishing has not been observed to cause changes in diversity of coastal invertebrates (observation). They further state that lack of environmental disturbance is a general property of coastal habitats (the model), which is why they are unaffected. They therefore propose or predict (the hypothesis) that introduction of this method of fishing will have no problems for diversity other than fish. Opponents argue that the local system is special and there will be declines in diversity if the chemical fishing is introduced.

Nevertheless, the Fisheries Department in the area has its way and chemical fishing is allowed. Measurements can be made to test the two predictions (no effect versus a decline in diversity). Two mistakes can occur. One (called Type I error) will be to declare that there is an effect, when really there is not one. In other words, there is no effect of fishing, but the data are imprecise and suggest a decline in diversity.

Alternatively, there may be a decline in diversity, but the information is imprecise and the effect of fishing is not identified. This is a Type II error. For sustainable use of the coast, Type II errors must be avoided. Type I errors are precautionary - an activity such as chemical fishing would be stopped even though it does no harm. A Type II error is an environmental decline by mistake. This does not conform to precautionary principles which require action to protect the environment when there is doubt (including imprecision). Preventing Type II errors absolutely requires clear hypotheses about what may change, when, how fast and by how much (Underwood 1997b).

(4) Monitoring often misses the things it is supposed to detect

Apart from logical, technical and statistical problems of ill-defined "monitoring" (i.e. collection of information for which there are no hypotheses or for which the variables are not well-defined in relation to the hypotheses being tested), there are issues of timing, frequency and spatial scales that should be measured. There is little point in reiterating the issues, which have been comprehensively covered elsewhere (Green 1979; Underwood 1989, 1991c, 1992). An example is shown in Fig. 3. The point is that routine sampling in the absence of explicit understanding of the processes operating, their time-scales, their spatial scales and their natural variability will never be a reliable or useful tool in the protection and conservation of coastal diversity.

It is, therefore, inevitable that people without detailed training in ecological processes, scientific logic, experimental design and statistical analysis will never be able to accumulate cost-effective, valid data about environmental change.

"Indicators" are popular, but not necessarily indicative

Another popular, but often ill-conceived component of amateur environmental monitoring is that there are indicators of more complex environmental variables. An indicator is a measure which stands in for a more difficult measure, but actually indicates what is happening to the other variable that is not being measured.

How to choose indicators has been described extensively elsewhere (e.g. Underwood and Peterson 1988; Keough and Quinn 1991). More recently, there has been progress in the technically complex area of how to choose manageable subsets of large, complex sets of species, so that the subsets show the same patterns of change through time as shown by the whole set (Clarke and Warwick 1997).

Some indicators are really surrogates - measures of something quite different from what is wanted. For example, quality of water (which is, in itself, a complex mix of quite different types of measurements) is often documented because it is supposed to indicate what is happening to ecological variables, which are more difficult to measure. In this case, there are numerous problems:

- it has been demonstrated that it is usually cheaper to make direct ecological measures than to measure indirect chemical and physical variables (GESAMP 1980; Marine Ecology Progress Series 1988). This does not, of course, fit with the ideals of community monitoring, where it is widely believed that unskilled observers can operate machines to take valid physical and chemical data. On the other hand, what is ideal about having expensive, indirect measures?
- it is remarkably unreliable to assume that biological diversity is driven or controlled by physical and chemical variables. This flies in the face of the long-standing, widespread demonstration that biological interactions, "supply-side" ecological process involving larval stages and local disturbances combine to maintain local diversity. See all the discussion earlier ("Biodiversity in coastal habitats..." section).

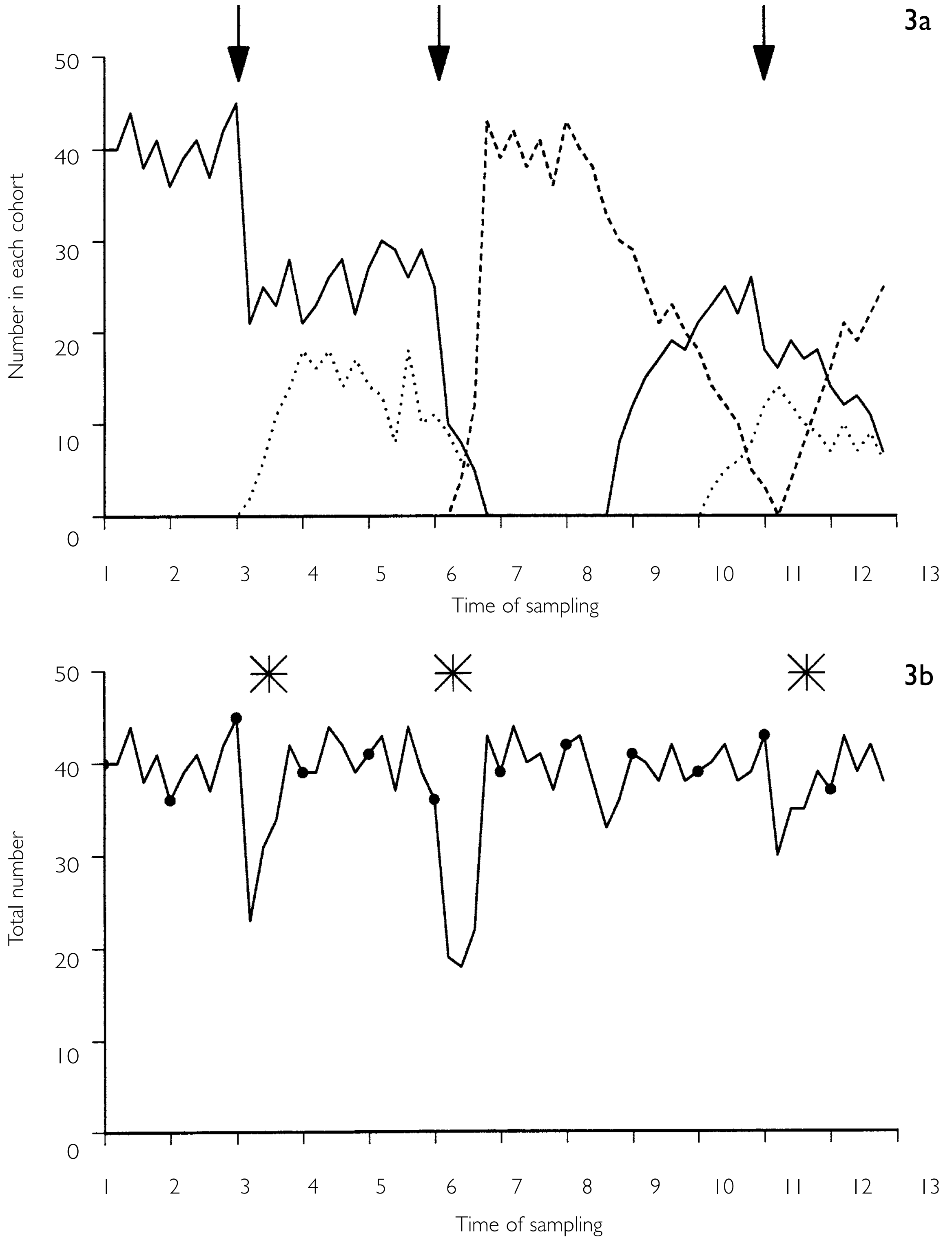

Figure 3. Routine monitoring is often done at fixed times, without knowledge of the processes changing populations and without clear hypotheses about what is needed to measure and why. In this example, a population is being counted (monitored) in order to detect environmental impacts that should cause decreases in abundances of the animals. The population is made up of different age cohorts, shown by different types of lines in (a). At various times, the numbers decrease because of environmental impacts (shown at the times with arrows). These are followed by rapid arrivals of new, young individuals. Only briefly are there actual decreases in numbers of the whole population (shown as asterisks in (b)). None of these is detected by changes in the counts of the whole population, because they occur in between the times of routine monitoring. This sort of monitoring fails to detect the impacts it is supposed to be for. This example is theoretical, but typical of the problems caused by lack of coherent thought about sampling real biological variables.

- any proposed indicator must actually have been demonstrated to be tightly correlated (positively or negatively) with the measure required, for which it is supposed to be an indicator. This is a *necessary* condition for an indicator to be useful (see Fig. 4). Thus, some measure of quality of water might be supposed to indicate environmental well-being, i.e. sustaining locally large numbers of marine species. For this to be true, there must be sensible and reliable evidence that any difference in quality of water is associated (correlated) with a difference in diversity. Better quality of water should have been shown to be associated with greater diversity.

  In fact, such a correlation is unlikely in estuarine and coastal habitats. The spatial scale at which quality of water is known to vary (100s of metres and larger scales) is much greater than the scales at which biological diversity changes (Chapman and Underwood 1997a; Underwood and Chapman 1996; Fig. 5).

- even if a correlation has been shown between the value of an indicator variable and the variable it is supposed to indicate, that is not enough. It is *necessary* for there to be a correlation. It is, however, not *sufficient* for a correlation to demonstrate any value of an indicator. An indicator may vary with diversity, creating a correlation, but not be a *cause* of changes in diversity. For example, the numbers and types of snails (gastropods) may be quite a good indicator of diversity in mangrove forests (this is an informative example, it is not claimed that gastropods *are* a good indicator). Under normal circumstances, numbers and types of snails rise and fall with numbers, types, diversity of all the species. At some later time, there may be chemical pollution in the mangrove forests, reducing diversity of worms, crabs, insects, etc. If gastropods are not sensitive to this pollution,

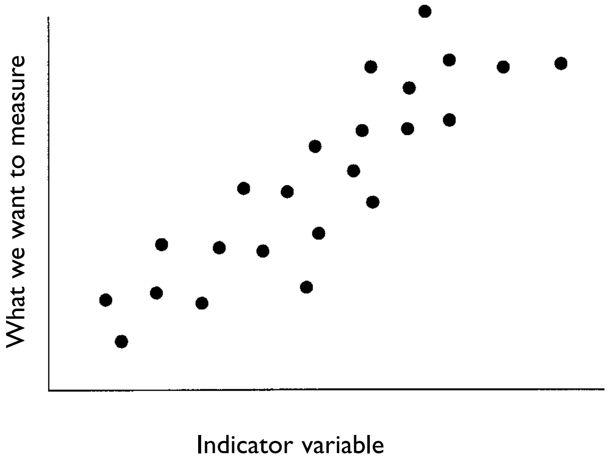

Figure 4. If an indicator is of any value to represent another, more difficult or more expensive form of measurement (the one we really want), there must, at least, be a correlation (as illustrated here for a theoretical example) between the two. This is not enough, but it is necessary (see text for details).

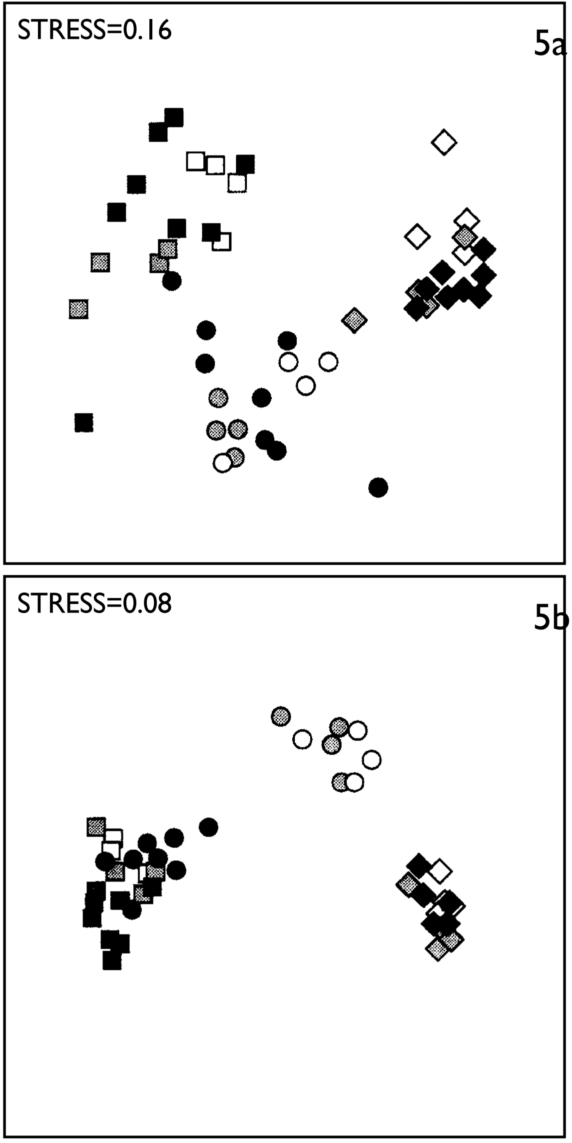

Figure 5. Patterns of diversity in assemblages of animals and plants vary in time and place and differently from one place to another. The data are nMDS plots, in which points near each other represent samples that are more similar in the composition of species (varieties and abundances) than are samples represented by points further away. Different symbols indicate different isolated patches of mangrove forest; different shading in the symbols represents four sites inside each patch of forest. (a) are data from 1995; (b) are data from 1996. Obviously, assemblages in the four sites in one patch (the circles) are less like each other at the second time, but the sites in the other two patches are more similar than at the first time. There are also more differences among patches at the second time of sampling.

their numbers will not change. If gastropods were being used as an indicator, they would not show the changes in diversity.

Most indicators proposed or used in coastal habitats have never been shown to be correlated with diversity. Demonstrating correlations requires careful and valid sampling of the proposed indicator and of biodiversity across the range of possible values each can take. Even where correlations have been shown, there are virtually no cases where it has been demonstrated that a change in biodiversity is matched by a corresponding change in the indicator variable (or vice versa). Demonstrating a predictable relationship between a supposed indicator and measures of biodiversity requires replicated, controlled ecological experiments. These are technically complex and it is only possible to design and interpret them by involving professional, experienced scientists.

Finally, some indicators are not obviously simpler or cheaper than a direct measure. As an example, turbidity of water is an indirect measure of how deep light reaches. The depth reached by light can be measured directly, so measuring turbidity does not simplify anything. The depth reached by light is supposed to be an indicator of how deep seagrasses can reach (and seagrasses are sometimes associated with relatively great diversity of animals and plants). It is, however, claimed that, because turbidity is a good indicator, reducing loads of sediment will reduce turbidity, thereby increasing the range of habitat for seagrass. This claim (which is an hypothesis) can be tested experimentally. It should be tested before expensive programmes of removal of sediments are done in the hope that seagrasses (and, indirectly, local diversity) will benefit.

How are ecological measures of diversity made, analysed and interpreted?

This is not the place to attempt to describe the issues that must be considered when attempting to measure spatial differences or temporal changes in biodiversity. This is a very complex and important topic. Apart from very clear hypotheses before one starts, there are specific requirements of any sampling programme. In summary, these are:

- clear and unarguable definitions of what is to be measured and where, when and in what circumstances (Green 1979); this is the definition of the "population" of measurements that are relevant (Underwood 1997a);
- precise and unambiguous definition of how measurements will be made, with respect to the methods (quadrats, nets, video, percentage cover, etc.) and why these are more likely to be representative of the flora and fauna than are other methods (Elliott 1977; Green 1979);
- a description of the size of the sampling-unit (quadrat, grab, transect, etc.), because spatial variation in abundance of animals and plants depends on the size of unit. There are numerous studies of the relationships between number of species found and amount of habitat sampled (for example, Hawkins and Hartnoll 1980; reviews by McGuinness 1984a, b);
- the design of sampling at each location, site and time. This involves the nature of representative sampling, i.e. the spacing and numbers of replicates. Replicates are needed to ensure that spatial variability is properly estimated (Green 1979). There are numerous problems in ensuring that appropriate replicates are available (see, particularly, Hurlbert 1984);
- demonstration that all attempts have been made to ensure that replicate units are independent (i.e. independence within samples) and, where there are examples at more than one place at a time, there is independence among the places or times in the sampling (i.e. independence among samples). Unless data are independent, there is usually no valid statistical method for analysing data. This is a complex and difficult topic, described in detail in Underwood (1997a);
- where sampling is done through time (the purpose of many so-called monitoring programmes), the times of sampling must be appropriate for the times of variation anticipated by the hypotheses (see Underwood 1991c; Morrisey *et al.* 1994);
- where changes in diversity are anticipated, but the spatial and temporal scales of variation are unclear, sampling must be at an hierarchy of scales that might be affected (Green and Hobson 1970; Underwood 1992);
- where sampling is done to determine differences through time in potentially impacted versus control areas, the sampling must be designed to maximize the probability of detecting the impact, if it occurs. This requires estimating the size of the statistical interaction between the potentially impacted and the control areas from before to after the impact (Green 1979; Stewart-Oaten *et al.* 1986; Underwood 1992).

These are well-known in environmental sampling. If they are not done properly, sampling is incompetent. Worse, the natural complexity, variation and patchiness described earlier creates particular difficulties for detecting any differences or changes in biodiversity. All the above considerations demonstrate why sampling that is ill-designed, illogical or otherwise incompetent is a waste of time, energy and resources. Worse, it provides no help for better environmental management or conservation.

All of the above considerations have been the focus of attention for at least 70 years for *univariate* measures, for example, numbers of a single species. Any evaluation of biodiversity involves *multivariate* measures, typically involving the counts of numbers of animals and plants in replicate sample units. Multivariate measures are more complicated and techniques of analysis are newer, evolving and needing testing for studies of biodiversity.

An example is given in Table 1 of the sort of information that must be gathered in any analysis of biodiversity. It shows the numbers (or other measures such as cover of substratum, sizes, biomass, etc.) of each species (or other taxonomic grouping, Clarke 1993) in each replicate unit in each sample. It does not matter if all that is needed is lists of species (data on the presence or absence of species); these are simply the number 1 (i.e. the species is present) or 0 (it is absent).

Samples must then conform to the above general requirements (independence, adequate replication, appropriate spatial and temporal scales). To date, this creates major difficulties for analysis of complex multivariate sets of data. Some excellent accounts of the problem have been given in Clarke (1993), Clarke and Green (1988), Green (1979) and Pielou (1984). There have been very recent developments of methods explicitly designed to deal with the complexity of measures of biodiversity in natural systems, to account for natural variability and interactions (e.g. Clarke and Ainsworth 1993; Legendre and Anderson 1999; Underwood and Chapman 1998).

The only point of relevance here is that professional ecologists are attempting *to deal with* the needs of design and analysis of sampling for measuring changes in coastal biodiversity. This is an on-going and rapidly-developing area of research. It is not possible to by-pass the needs for proper methods. Any attempt to gather information without attention to all of the above requirements must result in inadequate, incompetent, uninterpretable and useless information.

This is not conjecture. Scientists have known for decades the consequences of not collecting appropriate information (Chapman 1986; Connor and Simberloff 1979; Green 1979; Hurlbert 1984; Underwood 1981, 1997a).

So, assessments of differences and changes in diversity depend on current knowledge about methods, expertise in design and analysis of sampling and, increasingly, knowledge of complex statistical analyses, including training and experience in minimization of uncertainty, maximization of efficiency and how to interpret outcomes.

Table 1. Example of the sort of information needed to determine patterns in diversity of animals and plants. There are 3 different samples (for example, from 3 areas of the coast) and 4 replicates (cores or quadrats) in each sample. In every replicate, the numbers of all the species have been recorded.

	Sample 1				Sample 2				Sample 3			
Replicate	1	2	3	4	1	2	3	4	1	2	3	4
Species												
A	10	2	3	0	4	5	16	4	9	4	2	21
B	4	15	3	9	0	2	0	4	1	1	2	12
C	1	2	7	17	4	9	7	0	1	3	6	17
D	2	2	2	8	6	4	13	23	5	1	8	9
E	2	7	5	4	1	9	11	22	3	0	12	6
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Are there really problems if expertise is inadequate?

Several investigations of community and professional scientific involvement in acquisition of data in environmental issues have revealed various and often large problems. For example, Continuing Education Programmes in the University of Sydney (from 1984 to 1996 organized by the Institute of Marine Ecology) provided opportunities for more than 1,000 interested and dedicated people to be involved in the beginnings of quantitative study of coastal biodiversity. Long experience and the large numbers of people involved allow us to reach robust conclusions. Most of the core elements of sampling are counter-intuitive to most people and often came as a surprise to groups of people who were keen, relatively experienced and who thought they knew what they were doing. It is not possible to ensure that untrained people, without constant guidance, can take any sort of ecological measures that are unbiased (i.e. representative). Without considerable training, it is impractical to foresee amateurs, however enthusiastic and knowledgeable of the needs, being able to collect useful and precise data, let alone be able to analyse and interpret them.

Our experience allows examination of the effectiveness of two other, more qualified groups in environmental sampling. First are undergraduate students in classes learning about quantitative ecology. Our data-base here covers the period from 1974 to 1997. It involves a total of approximately 1,500 students, majoring in subjects requiring suitable mathematical backgrounds who have chosen ecological topics as their primary subject in their final year of study. All have been involved in at least 140 hours of face-to-face teaching (residential field courses, lectures, tutorials and practical classes). This experience demonstrates that it is possible to instil adequate understanding of the fundamental components of sampling (replication, independence, representation, some of the inherent problems). So, an investment of this order of training provides a minimal ability. It also demonstrates that it is difficult to imagine this amount of training being sufficient to guarantee reliable information from such graduates without considerably extended guidance and informed advice.

The latter point can be illustrated by experience with an interactive, community-based programme to sample people's perception and uses of coastal environments. "Project Aware on the Rocks" is a major programme of public awareness and education about consequences of foraging on rocky shores (Chapman 1997). The project is based on herculean efforts by Cathy Hemery, in association with Pittwater Council, the Institute of Marine Ecology (University of Sydney) and a broad range of helpers, supporters and funding agencies. It has run for many years and involved numerous members of the public. One component (now ceased through lack of funding) was surveys of people using the shores; this was part of a larger study (Chapman and Underwood 1997b).

Throughout, to maintain integrity and reliability of data, it was continuously necessary to re-orientate the volunteers, to organise for them the dates and timing of sampling and to examine carefully the data. Despite very close collaboration and partnership with professional ecologists, there were illogicalities and inconsistencies in the information. For example, on several occasions, questionnaires were filled in by the trained personnel in the Project that simultaneously recorded zero people collecting bait, but listed the species taken as bait by the people present! Alternatively, despite recording people taking bait, no entry was made for what they took. Such inconsistencies made it impossible to trust the information without further checking and validation, on a daily basis. How can the necessary reliability be achieved in the absence of constant expert guidance and input (see also Chapman 1997)?

This sort of problem is extremely widespread. Consider the much better established and long-standing programmes to survey diversity of species of birds. These are usually well-resourced. The limited number of species in any geographic region allows dedicated and knowledgable observers to become highly skilled in identifying and estimating numbers of birds. Despite this, there are well-documented major problems in any attempt to analyse the data (e.g. Thomas 1996). One specific problem is that data are not free of biases. As illustrated in Fig. 6, the numbers of birds believed to be present in an area change through time and with any change in the observers. It is never possible to know whether the apparent changes indicate real changes in numbers in the population (Bart and Schoultz 1984; Sauer *et al.* 1994). Properly trained and experienced observers were consistent in their measurements and therefore relatively consistent through time, but under-trained observers

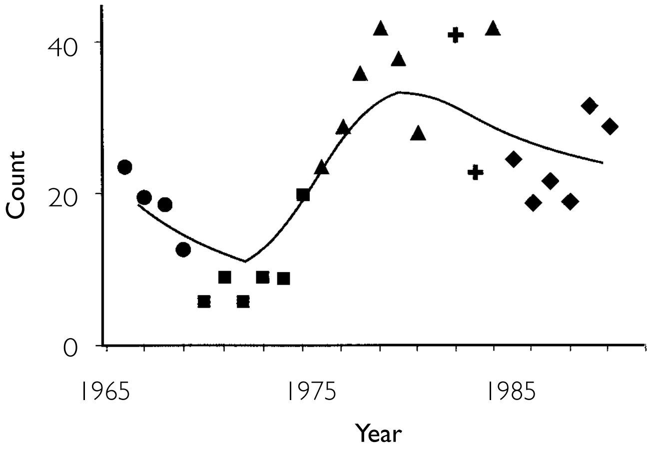

Figure 6. Estimated numbers of birds change through time, simultaneously with changes in the observers (each observer is shown by a different symbol).This is not likely to represent real natural changes in abundance. It indicates that untrained observers produce unreliable results (from Sauer *et al.* 1994; see text for details).

provided useless data (Faanes and Bystrak 1981). As a consequence, where untrained observers get into the projects, it is not possible to be sure of which species are present - diversity is also in the eye of the beholder. Different observers see the birds differently. As a result, despite the excellence of amateur ornithologists, the necessary quantitative data are largely unreliable and, for some stated purposes, useless.

What chance then, is there that non-professional data-gathering (i.e. "community monitoring") will be better in much more complex sets of species? For coastal organisms, there are grave taxonomic difficulties and little to no history of widespread skills in or knowledge of the animals and plants. The habitats are almost always difficult to access. Diversity is great, but variation is also great.

It is not actually surprising that there are problems. Quantitative ecology has long been recognised to be a difficult topic. For example, Hurlbert (1984) identified that approximately 25 - 30% of ecological studies in major scientific journals had fundamental problems of replication. Similar difficulties have been encountered in logic, analyses, etc. (e.g. Dawkins 1981; Underwood 1981). This occurs despite independent, external reviewing of all such papers by identified experts who remain anonymous so are able to be forthright in their criticisms.

This sort of problem does identify that there will inevitably be problems for any data-gathering, if attention to the logical structure, sampling requirements and appropriateness of methods have not been very carefully considered. This requires considerable training, experience and external review of relevant procedures, frameworks and planning. It is extremely unlikely that the problems will be avoided by those who have no training in what are the difficulties. Professional ecology is, in fact, improving the validity of observations and analyses because of the constant attention and criticism of every publication. It always requires constant vigilance and renewed inputs from those with training and expertise. Under these circumstances, apart from the advantages of involvement, awareness and commitment, it will almost always be cheaper, more cost-efficient, more reliable in the long term to have the quantitative ecology done by quantitative ecologists.

Conclusions: integrating community and professional roles

We clearly need a better model for the future well-being of our coastal habitats. To deny the preceding summaries requires demonstration that they are factually incorrect - not just that they are unwanted or unpalatable. Opinion that systems are simple enough not to need professional attention is contrary to precautionary principles, violates all documented analyses of complex systems and destroys any opportunity to provide real solutions to problems of environmental degradation and development. Devoting resources from public funds to public science without the normal processes of review, critical analysis and searches for improvements or better alternatives promotes unaccountability. This is extremely unfortunate given the shortage of resources generally available for increasing environmental knowledge.

We must have a better way forward that achieves the aims of legitimate public concern. We must stop the current distrust of agencies, remoteness of professional scientists and lack of realization in the general community of what is the basis for useful and practical scientific contributions to the long-term social and political issues of conservation of biological diversity.

We recognize that a new form of partnership and collaboration is needed. It requires the community to remain active in the determination of issues and priorities. This is a crucially important task and one that obviously cannot be devolved to governments, agencies, bureaucracies. Whenever and wherever such priorities are determined, there needs to be involvement of professional environmental scientists in the planning of strategies to achieve the defined aims. This includes identification and interpretation of available data (the observations) and assessment of opinions about proposed solutions, including anyone's proposals (the models). There must then be agreement about predictions (the hypotheses, particularly those that are necessarily quantitative). Finally, sampling programmes must be designed to gather the necessary information. This will include identification of assumptions, gathering preliminary estimates of variation (by appropriate pilot studies), determining how data must be analysed, calculating power to detect predicted differences and changes (wherever possible, in relation to specific needs and predictions).

Above all, during the planning, there must be explicit procedures to ensure that outcomes of data-gathering are interpreted and described:

- exclusively for the purposes agreed by those who have initiated the programme - the users of the information. It is too easy for professional scientists to hijack a research programme for their own ends (see Ludwig *et al.*'s (1993) criticism of the environmental research programmes advocated by the Ecological Society of America). External, open review by other experts is the best way to prevent this;
- entirely in terms, forms, documents and other deliverables that are readily available to and interpretable by the members of society who want them.

At present, professional ecologists are excluded from many community projects, either by ignorance or political grand-standing by the groups themselves or because of insularity and lack of openness by governmental agencies or because of bureaucratic manipulation by the "rules" of funding bodies (see Environmental Trusts, Guidelines for Grant Applications 1998, which do not allow professional scientists to apply for funds, which are only available for community organizations).

If confronted by a plumbing problem, would you rather call a plumber - trained, currently certified, skilled and experienced, who can bring all the tools, fittings and fixtures? Or would you rather call in an apprentice plumber? Or someone who has read manuals about plumbing? Or someone who does his/her own plumbing regardless of the consequences? Or, perhaps, you would prefer to consult someone who imagines that they could know about plumbing, simply because they know about something else? Or, most of all, would you consult someone who does not recognise that plumbing is relevant and necessary to prevent us being smothered in sewage?

Replace the problem in the previous sentences with any problem of environmental change and replace "plumber/plumbing" by "ecologist/ ecology" and determine where you then find yourself. We can continue without proper and full collaboration of the necessary scientists. Ecologists who are useful for helping document and understand changes in diversity are not self-proclaimed. They are those who have training and experience in the relevant quantitative issues. Useful discussions of what is an ecologist can be found in Connor and Simberloff (1986), McIntosh (1985), Peters (1991), Shrader-Frechette and McCoy (1990), Simberloff (1980). The most succinct way of determining whether a person is an appropriately skilled ecologist is to determine not just what they claim to know, but what work has been done to know it. This includes accepted publications in peer-reviewed scientific journals. These constitute work that uniquely defines a scientist (Merton 1977).

Many scientists are not aloof from the issues, but there is no doubt that they (we) are being excluded. Scientists will, however, be involved. In any open, democratic society, expertise will inevitably be brought to bear in reviewing and commenting on any outcomes of community monitoring. For these to be successful, considerable care and expertise must go into the planning, implementation and interpretation of any programmes, or they must be found unscientific and unsatisfactory. It would make more sense to have professional expertise in projects when they are planned and done, rather than pointing out what went wrong (and why) afterwards.

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QUESTIONS & ANSWERS

SUE BRIGGS: I couldn't agree with you more about community monitoring, especially in relation to bird surveys, and I have made those views known and got myself into hot water. But community participation is quite different. In this model, scientists start by engaging the community, as you said, and find out what people want. Then we do the research, we talk with the community the whole time, and then we cross-test our ideas with their views.

Farmers, in particular, I think, are extremely good observers but dreadful interpreters, so you don't take any notice of their interpretations but you take an awful lot of notice of what they have observed. So in this model we have a more engaged role, a more active role for the community. It is not monitoring. It is a reality check on what we think we are finding out.

GEE CHAPMAN: Yes, but the amount of money that is going into useless monitoring, especially water quality, is still a problem.

LIZ DENNY: Surely, it doesn't matter how exact and precise your science is, you could still go any time and find a tourist hotel and a marina built on your study site. But when you are presented with a situation like this and you have a research site that you feel is really important to be maintained, you can talk until you are blue in the face about your research, but the only thing that is going to save your site is the community saying, "Hang on, this is fabulous. We have been involved in this research project for a million years and it is really worth maintaining." Do you think the community has a role like this, or not? Do you think we should give them a miss completely?

CHAPMAN: Not at all. I think they have an important role because what we want to preserve, what we want the next generation to have, is a community value. This is not a scientific value. The problem is when the community does not hand the science over to people who can do it, to assess whether what the community values is being achieved or not.

DENNY: Can't they even ask questions?

CHAPMAN: To some extent they can, but the questions are often based on very old-fashioned science like equilibria and the balance of nature that we learned about 100 years ago and don't believe in any more. I'm not fussed with people asking these questions. I think they should be, and if we cannot explain our science then we are at fault, there is no doubt. The thing is, the community is not encouraged to recognise what is a scientist and what is not a scientist, and think they can answer all the questions.

I put up that list of publications at the beginning [of my talk] because a scientist is someone who does science, not someone who puts on a green T-shirt. Appreciation of this difference is missing, and one reason it is missing is because of the media, because they don't know the difference either.

NANCY PALLIN: My concern is that if you want scientists to come and help you with a community project, it's not that simple. They are very busy people. They also like to be paid, which is by definition the difference between a community person and a scientist.

Now, if you can't get funding from NHT for some scientific assessment of a project, you don't have it at all. Okay? I've got money for getting trees in the ground, but if I had put frilly bits like actual scientific assessment into my application, I don't know whether I would have got funded or not. I would like some scientific help. It's bloody scary out there!

CHAPMAN: I am pleased to hear that, but I will make a couple of points. The first is about payment. Lots of us don't get paid, and never have been paid for community work. Secondly, a number of community people who are sitting on total catchment management committees and various other committees are paid. So it is not a simple case of only scientists being paid; but sure, we are busy.

PALLIN: But you do need to be paid, I think.

CHAPMAN: That would be very nice, and for some things we are. If you approach scientists and they knock you back, then, I can understand why you are striking out by yourselves, but to a large extent that is not the case and as was said earlier with NHT funding, scientists are excluded from projects at the outset. The new ETF rehabilitation restoration guidelines specifically exclude scientific partnerships. They exclude them.

PALLIN: So we have to change that. That's what it amounts to.

CHAPMAN: Yes, you have to change it because we are all shouting about changing it, but the community is grabbing the money and running.

PALLIN: I am a community person and this is the first time that I have heard this. We need to have this cross-fertilisation going on to a much greater degree. You are busy doing your science and we are busy doing the community stuff, but we are not really getting adequate cross-referencing, unless we - as individuals - turn up at something like this.

My other question is: what about the New South Wales Biodiversity Strategy? Does that, for example, put an emphasis on restoration based on manipulating the natural system with fire or whatever, rather than planting? What does the policy say?

CHAPMAN: I am not the appropriate person to answer that. I don't know if anyone else in the audience is. I am a marine ecologist. Does anyone have a comment? No? I might say one thing; I did sit in on a couple of meetings of the biodiversity community group program in which they stated time and again that they had no intention of seeking scientific interaction. At one meeting it was actually stated at a meeting that all biodiversity surveys for any development in New South Wales were to be done by community groups because that was the only way to get true, accurate information. I give you that. I was there.