MONITORING ECOLOGICAL CHANGE IN WETLANDS

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Abstract
The adequacy of monitoring of aquatic and wetland habitats has received a great deal of attention in recent years. This attention has arisen as the awareness of the extent of ecological change in these habitats has changed. However, this awareness has not always been accompanied by an adequate understanding of the intricacies of planning and implementing monitoring programmes. As a starting point, more attention to the design and implementation of monitoring programmes is required. This includes careful consideration of the objectives, the statistical reliability of the sampling approaches and data analysis, and effective utilisation of the results. Conservation of wetlands requires that not only are effective monitoring programmes implemented, but also that the results are effectively utilised. Monitoring of ecological change in wetlands can be undertaken at several levels and with vastly different techniques. Satellite imagery, often linked to a GIS, aerial photography, flora and fauna surveys at the species and community levels, physico-chemical analyses, ecotoxicological testing, and biomonitoring instream and bank-side all have particular advantages and disadvantages. The choice of techniques is dependent on the objectives of the monitoring programme and the nature of the site being monitored.

Finlayson, C.M.: **Monitoring von ökologischen Veränderungen in Feuchtgebieten**
Monitoring in Feuchtgebietshabitaten hat in den letzten Jahren beträchtliche Aufmerksamkeit erregt. Diese Aufmerksamkeit begründete sich im Ausmaß der ökologischen Veränderungen in diesen Lebensräumen. Dieses Bewußtsein war jedoch nicht immer mit einem angemessenen Verständnis der Planung und Durchsetzung von Monitoring-Programmen verbunden. Von Beginn an muß dem Design und der Durchsetzung von Monitoring-Programmen mehr Beachtung beigemessen werden. Das umfaßt eine sorgfältige Überlegung der Zielvorstellung, der statistischen Zuverläßigkeit der Sammelmethoden und Datenanalyse und eine wirkungsvolle Umsetzung der Ergebnisse. Schutz von Feuchtgebieten bedeutet nicht nur, daß wirkungsvolle Monitoring-Programme eingesetzt werden, sondern daß deren Ergebnisse wirkungsvoll umgesetzt werden. Monitoring von ökologischen Veränderungen in Feuchtgebieten kann auf verschiedenen Ebenen und mit sehr unterschiedlichen Techniken durchgeführt werden. Satellitenbilder, oft mit GIS verbunden, Luftbildfotografie, Dokumentation von Flora und Fauna auf dem Art- und Gesellschaftsniveau, physiko-chemische Analysen, ökotoxikologische Tests und Biomonitoring haben bestimmte Vor- und Nachteile. Die Auswahl der Techniken ist abhängig von den Zielen des Monitoring-Programmes und von der Art des Untersuchungsgebietes.

Finlayson, C.M.: **Monitorování změn ekologického charakteru mokřadů**
Monitorování vodních a bažinných stanovišť získalo v posledních letech mnoho pozornosti zejména co se týče jeho přiměřenosti. Tato pozornost vzrostla s uvědoměním si rozsahu změn ekologického charakteru těchto ekosystémů. Ne vždy je však do důsledku chápána složitost plánování a realizace monitorovacích programů. V prvé řadě více pozornosti je třeba věnovat vypracování a realizaci monitorovacích programů, což zahrnuje pečlivé posouzení účelu monitorování, statistické průkaznosti navrženého systému získávání a zpracování dat a efektivní využívání výsledků. Ochrana mokřadů vyžaduje nejen efektivní monitorování, ale také efektivní využívání obdržených výsledků. Monitorování změn ekologického charakteru mokřadů může být prováděno na několika úrovních s použitím celé řady metod. Družicové snímkování často napojené na geografické informační systémy (GIS), letecké snímkování, inventarizace flory a fauny na úrovni druhů či společenstev, fyzikálně-chemické analýzy, ekotoxikologické metody, bio-monitoring prováděný v toku či na břehu řeky, všechny mají své přednosti i nevýhody. Výběr metody je závislý na účelu monitorovacího programu a charakteru sledované lokality.

INTRODUCTION

The adequacy of techniques for monitoring of aquatic and wetland habitats has received a great deal of attention in recent years (e.g. MAHER & NORRIS 1990; MOSER et al. 1993; SPELLERBERG 1991; HESS et al. 1990). This attention has arisen as the awareness of the extent of ecological change in these habitats has increased. For example, the Ramsar Convention has recognised the need to address change in the ecological character of internationally important wetlands. Article 3.2 of the Convention states:

> **"Each Contracting Party shall arrange to be informed at the earliest possible time if the ecological character of any wetland in its territory and included in the List [Ramsar List of internationally important sites] has changed, is changing or is likely to change as a result of technological developments, pollution or other human interference".**

However, technical guidelines that can be used to determine what constitutes ecological change in wetlands do not exist. Furthermore, it is extremely difficult to ascertain what constitutes an unacceptable change in the ecological character of a particular wetland type or site.

As a consequence of the Ramsar initiative in identifying the concept of ecological change in wetland conservation the International Waterfowl and Wetland Research Bureau (IWRB) organised a workshop on this topic and came up with a number of general conclusions (FINLAYSON & VOLZ 1993):

i. over the past 30 years, in particular, human-induced ecological change has been extremely detrimental to wetland functions and values;
ii. as a concept, ecological change involves scientific and political considerations;
iii. in the majority of cases, ecological change is a consequence of the wider social and economic factors that operate outside the boundary of the wetland; and
iv. ecological change can be identified by regular monitoring of selected parameters and by comparing the results with an established baseline.

These conclusions have been the basis for developing a specialist group to address specific aspects of determining the extent of ecological change in wetlands and how such change can be monitored (see MOSER et al. 1993). This is being done in parallel with the Bureau of the Ramsar Convention and a further IWRB specialist group looking at aspects of wetland rehabilitation.

The same workshop went on to address techniques being used to measure ecological change and the extent of understanding of the concept of ecological change. One conclusion was that whilst there were problems in choosing and applying appropriate techniques for monitoring, the absence of appropriate institutional frameworks under which to conduct monitoring programmes was a more severe problem. Similar comments were made in a summary of a workshop held in the Czech Republic on wetlands in agricultural and forested landscapes in Central Europe (FINLAYSON 1992a). Such criticisms also extend to institutional arrangements for wetland management in other regions of the world, with the Mediterranean Basin (PAPAYANNIS 1992; GARCIA-ORCOYEN 1992; HOLLIS 1992; VALAORAS et al. 1992) and the Lower Volga in Russia (SEDOV 1992; CHUIKOV & SITNIK 1992; FINLAYSON 1992b) being two glaring examples relatively close to Middle Europe.

The above criticisms are not confined to national agencies, with the Ramsar Convention also receiving criticism (e.g. PAPAYANNIS 1992). For this reason, it is particularly relevant that the initiative for addressing the difficult technical and conceptual issues of **"change in ecological character"** of wetlands is being spearheaded by the Bureau of the Ramsar Convention and linked to regional programmes, such as that developed in the Mediterranean under the banner of MedWet, a cooperative wetland programme that developed from the so-called Grado Strategy for Managing Mediterranean Wetlands and Their Birds for the Year 2000 and Beyond (ANON. 1992; HOLLIS et al. 1992; FINLAYSON et al. 1992).

ECOLOGICAL CHANGE IN WETLANDS

Concept and definition of ecological change

DUGAN & JONES (1993) considered the concept of ecological change in wetlands by looking at the components that define the ecological nature of a wetland. Their view was that the ecological nature of a wetland was the sum of the functions, products and attributes which give the wetland value. These, in turn, were the product of the interchange between the biological and physical components of the ecosystem. They then defined ecological change as **"alteration of the biological and/or physical components of the ecosystem, and/or the interaction between them, in a manner which results in a reduction in the quality of those functions, products and attributes which give the wetland value to society"**.

The ecological character of wetlands can be altered in a diverse number of ways: drainage, pollution and eutrophication, overfishing and hunting, dam and barrage construction, water extraction, canalisation and diversion of waterways, and the introduction of pest species to name a few. DUGAN & JONES (1993) also concluded that the processes that lead to ecological change could be combined into three general groups:

i. Changes in the water regime: dams and water extraction, including groundwater, alter the hydrological regime; eutrophication and pollution alter the cycling of energy and productivity capacity of the wetland; and dykes and canals have increased flow rates along channels, reduced seasonal inundation of floodplains and increased the risk of floods.
ii. Physical alteration: specific activities that replace wetlands with agricultural, urban or industrial land; drainage, infilling, polder construction and conversion to aquaculture ponds are all intentional changes that can destroy wetlands.
iii. Biological change: over-utilisation of specific plant and animal species through fishing, hunting and harvesting can be devastating; additionally, the purposeful or accidental introduction of exotic species can result in intractable change.

All these processes reduce the value of wetlands. On this basis the IWRB workshop on this subject considered that ecological change should be interpreted only in the sense of negative/adverse impacts (FINLAYSON & VOLZ 1993).

Extent of ecological change

The extent of ecological change in wetlands of Middle Europe has yet to be ascertained. DUGAN & JONES (1993) point out that of the 45 Ramsar sites in Eastern Europe (in September 1992) 20 (44%) were reportedly undergoing ecological change. In Western Europe there were 321 listed sites with 175 (55%) undergoing change. Whilst these figures may seem high for sites that are supposedly of international importance, the real situation for all wetlands could be far worse as the analysis does not cover the large number of sites not listed under the Ramsar Convention. Information on the many important wetlands not listed under the Convention is not generally available despite the obligation for Contracting Parties to the Convention to make wise use of all wetlands and to develop a national wetlands policy.

An initial analysis of wetland management issues in Central and Eastern Europe was undertaken during a workshop in Třeboň in the Czech Republic during March 1992 (FINLAYSON 1992c). A series of workshop sessions was used to address the major threats and management issues in wetlands (peatlands, floodplains and fish ponds) in this region. The key points raised in these workshops (see summary in FINLAYSON 1992a) provide the basis of an assessment of the major factors causing ecological change in wetlands in this part of Europe (see diagrammatic summaries in Figs 1 and 2). These factors are essentially the same as those that result in the loss and degradation of wetlands in many parts of the world (see FINLAYSON & MOSER 1991; FINLAYSON et al. 1992; DUGAN 1990; MALTBY 1991; DUGAN 1993; MOSER & VAN VESSEM 1993).

As a prelude to monitoring ecological change in the wetlands of Middle Europe, a more thorough analysis of the status of the remaining wetlands is necessary; that provided in FINLAYSON (1992a) is not comprehensive. This analysis can then be used as the basis for assessing the need for monitoring programmes to provide early warning of further likely ecological change. To be truly effective, this analysis should be done through official agencies augmented by non-governmental sources as was successfully done in the Mediterranean basin (see ANON. 1992; FINLAYSON et al. 1992).

Underlying causes of ecological change

In addition to addressing the individual causes of ecological change in wetlands, the inadequacy of institutional structures should also be addressed. These inadequacies have been well highlighted in a number of cases from around the world (e.g. ANON. 1992; FINLAYSON 1992b; HOLLIS 1992; WILLIAMS 1991; DIEGUES 1992; MONTES & BIFANI 1991) and are not unique to any one region. In the context of monitoring to detect ecological change in wetlands, these inadequacies are extremely important and often reflect the economic, political and social constraints under which ecological management must operate. HOLLIS (1992) expresses this in the following way: **"This loss and degradation is rooted in social, economic and political processes. These operate behind a chimera created by the immediate causes of wetland loss whilst the apparent causes of wetland loss, such as the often quoted agricultural intensification and tourism, etc., are merely the outward expression of the underlying factors."** Furthermore, HOLLIS (1992) points out that merely tackling the apparent causes of wetland loss and degradation will not solve the problem and **"There has to be an offensive on the social, economic and political causes of wetland loss and degradation....."**. This theme is also evident in an assessment of the role of social factors in wetland management done by MERMET (1991).

These underlying factors are not directly the subject of this workshop on monitoring of ecological change in wetlands in Middle Europe, but they do have a pervasive influence on the effectiveness of procedures for monitoring. The purpose of mentioning these underlying factors is to highlight the urgent need for addressing them whilst also undertaking valid and scientifically rigorous monitoring programmes.

KVET (1992) has pointed out that sectoral management with little regard for other sectors has been a feature of recent wetland management approaches in some Middle European countries. Unless the political, social and economic processes behind this sectoral approach to wetland management are addressed, no amount of monitoring

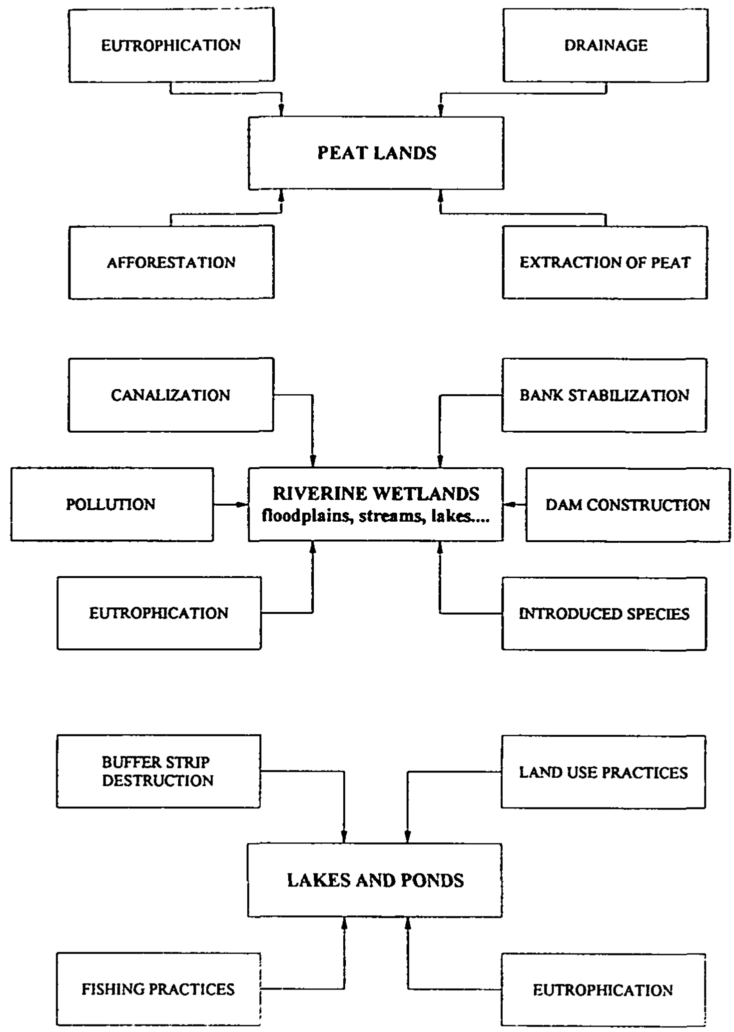

Fig 1.: Reasons for the loss and degradation of peatlands, floodplains and fish ponds and lakes in Central & Eastern Europe (from FINLAYSON 1992a).

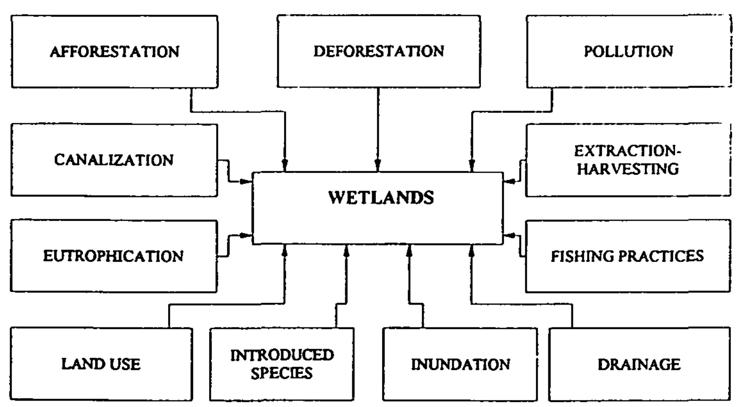

Fig. 2: Reasons for the loss and degradation of wetlands in Central & Eastern Europe (compiled from FINLAYSON 1992a).

will be able to stop, let alone reverse, the current rate of wetland loss and degradation. Reversing wetland loss may seem like an unachievable target, but it has been adopted as a goal in the Mediterranean (ANON. 1992; FINLAYSON et al. 1992; HOLLIS et al. 1992), the Lower Volga (FINLAYSON 1992b) and Australia (DONAHUE & PHILLIPS 1991); indicating a high level of commitment to wetland conservation.

Monitoring of ecological change is only one aspect of wetland management and should not be seen in isolation.

OBJECTIVES OF MONITORING

Framework and guidelines for monitoring

Before an effective monitoring programme can be implemented, the objectives of the programme must be clearly identified and agreed. In an ideal situation, this should be a straightforward and cooperative process between managers (who make decisions) and scientists (who provide expert advice and interpret the data). In a simple sense, the managers would outline the need for a monitoring programme and the scientists recommend the most appropriate techniques and, by an iterative process, an approach that has both scientific rigour and meets the management objectives will be developed. Conflict could arise if, in outlining the objectives, the managers are constrained or influenced by factors other than scientific considerations. Under such circumstances it must be remembered that any deficiency in the objectives will influence all other components of the programme (SPELLERBERG 1991).

MAHER & NORRIS (1990) have presented a framework (Fig. 3) for designing a water quality assessment programme using bioindicators; this could equally well apply to other monitoring programmes.

The starting point of this framework is the formulation of specific objectives for the programme; these would normally be more specific than the overall goals of the agency concerned. In presenting guidelines for assessing scientific programmes, SMITH

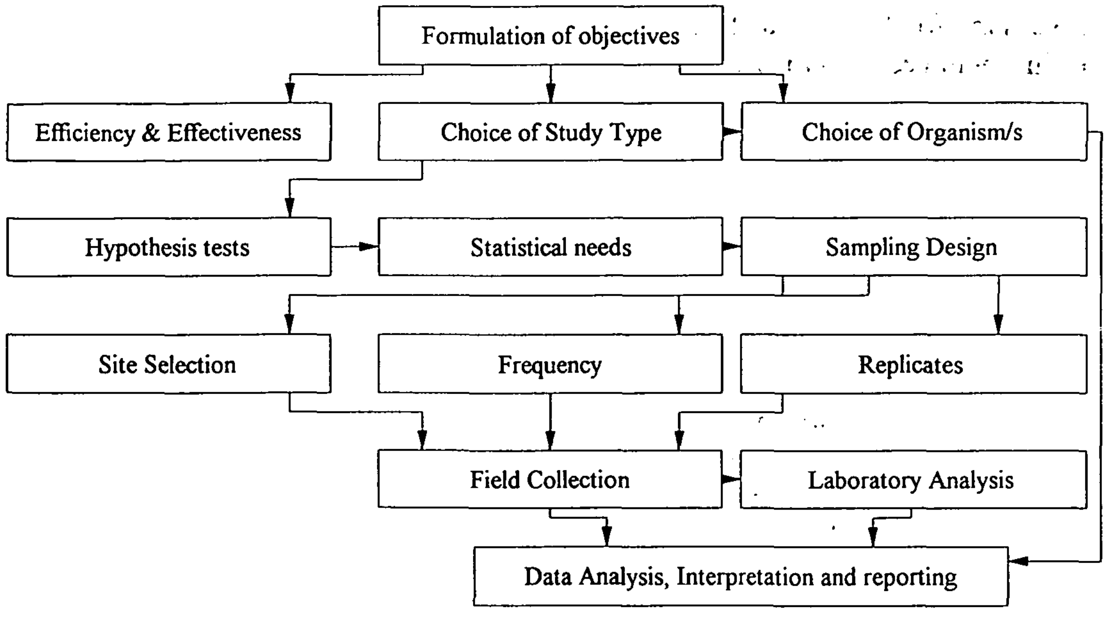

Fig. 3: A framework for designing a monitoring programme (based on that prepared for assessing water quality using bioindicators as presented by MAHER & NORRIS 1990).

(1985) stated that the objectives should be clearly and concisely defined, specify what is to be achieved, deal only with attainable results, and indicate when each stage will be completed. In water quality monitoring it is all too common to hear (but not read in published accounts) of chemical sampling programmes that continued for decades before any data interpretation was undertaken, and then, when it was belatedly done, to discover that the data either had very little value or could not provide the information originally being sought! Sadly, such reports are not uncommon.

Utilisation and interpretation of monitoring data

Before the objectives of a monitoring programme can be finalised, it goes without saying that the purpose of the programme should be determined. Equally important, but less frequently done, the processes for utilising and interpreting the data need to be agreed. In other words, will the processes for providing the data be appropriate for the decisions that will need to be taken and will the data be compatible with other data to be used in the decision making process? It is also important to reiterate that the data must be available in sufficient time for management decisions to be discussed and agreed. Thus, in terms of the diagram given by MAHER & NORRIS (1990), due emphasis must be given to setting and testing valid hypotheses, and methods for analysing, interpreting and reporting the data. SPELLERBERG (1991) emphasises the need to carefully assess data collection methods, etc., and to undertake a pilot project to determine whether or not the programme is feasible (Fig. 4).

Explicit statements of what is to be achieved are essential. This not only assists in defining the data collecting programme, but in long-term programmes also enables new staff to continue the work in a consistent manner. Objectives that simply state to "assess significant change" are not explicit and need to be revised to define the required level of significance. Often the level of significance is not defined, and yet, the level of significance expresses the very basis of the ecological rationale for undertaking a monitoring programme. Is it possible to implement an effective monitoring programme without determining what level of change is acceptable? Environmental data contains a certain amount of variability, but when does this variability reflect a real ecological change and is this change acceptable? These questions can be rephrased in a number of ways, but essentially, they can only be answered by an expression of societal attitudes (as interpreted by the agency undertaking the programme) towards the value of the habitat or ecosystem being monitored.

In a general sense, monitoring is needed to prevent further unchecked exploitation and degradation of wetlands. Thus, there is a need to assess the impact of human development and minimise ecological change. Success in such programmes will depend on our ability not only to detect and monitor changes in the quality of wetlands, but also to provide early indications of likely change and thereby take action to prevent this change from occurring. A monitoring programme that simply shows that change (including habitat loss) has occurred can have immense educational and public awareness value and demonstrate environmental trends, but programmes that enable steps to be taken before such change (or loss) occurs are urgently needed. Without these programmes the extent of ecological change (and loss) referred to above will continue unabated.

MONITORING ECOLOGICAL CHANGE

Techniques and baselines

An array of monitoring techniques for detecting ecological change in aquatic / wetland habitats exist and are being used

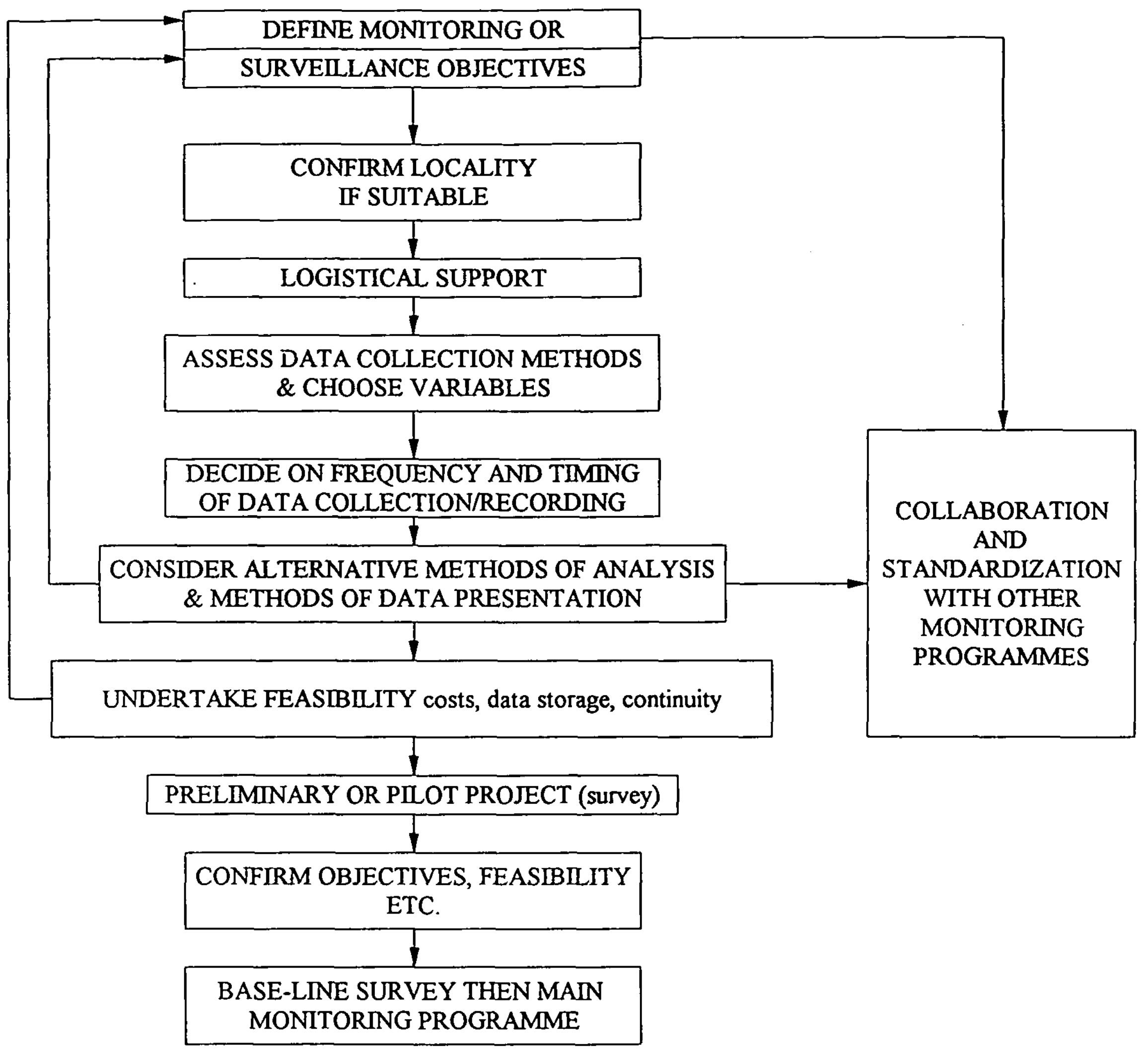

Fig. 4.: Conceptual plan for a monitoring programme (from SPELLERBERG 1991).

in different parts of the world (see papers in MOSER et al. 1994). The choice of appropriate techniques can be influenced by a myriad of reasons, but it needs to be reiterated that the technique(s) chosen must be able to satisfy the objective(s) of the monitoring programme. The technique is the tool by which the monitoring objective is achieved. In some circumstances, a suite of techniques may be required to avoid obtaining incorrect conclusions, although this depends on the resolution of particular techniques and the type of change being monitored. Complementary techniques can be used to firstly detect changes in ecosystem structure and function and secondly, to diagnose the reasons for such changes (e.g. US Fish & Wildlife Service Status and Trends Survey).

With all monitoring techniques there is a need to establish a starting point or obtain baseline data. Changes in ecological character need to be related to a baseline that identifies the key functions and values of the site. Thus, the functions and values of a particular site need to be defined and a baseline established. The functions and values of wetlands have been well elucidated in recent publications (e.g. DUGAN 1990, 1993; MALTBY 1991) and need not be further addressed here. Rather, it is more important to emphasise that establishing the baseline is an essential prerequisite for a monitoring programme; ecological change can not be quantified without a basis for comparison. SPELLERBERG (1991) considers baseline data to be information collected from the same place and on the same basis as subsequent data and that this is different to reference data which may have been collected previously. Reference data should only be used where it is not possible to obtain valid baseline data. To obtain a direct analysis of the extent and ecological significance of change a valid baseline is needed. However, for all sorts of reasons it may be necessary to use the more indirect method of comparing to reference data. This still has value, but care should be used when inferring from one site to another without statistical validation.

Integration of techniques

A number of techniques for monitoring ecological change were described in the IWRB workshop on this topic (FINLAYSON & VOLZ 1993). It is not the purpose of this paper to describe all possible techniques. Rather, a general introduction to remote sensing and biological monitoring techniques is given. These two broad techniques represent different levels of monitoring. Whilst a certain degree of information can be obtained from biological monitoring techniques, their real value is often enhanced by linking them to physico-chemical monitoring techniques. Thus, it is necessary to integrate the results of several techniques to achieve a thorough understanding of the nature of an ecological change and the most likely causes. Similarly, satellite data require some ground-truthing and linking to field surveys (e.g. vegetation distribution) before effective and reliable interpretation of the imagery can take place.

The above points serve to illustrate the complementary nature of different monitoring approaches. Under some scenarios it is not unreasonable to expect that monitoring schemes could be comprised of several complementary techniques; probably the most common would be biological surveys with physico-chemical surveys. Alternatively, a more sophisticated approach for monitoring point source water pollution is provided by that developed by HUMPHREY et al. (1990, 1994) in the Alligator Rivers Region of Northern Australia, where pre-release toxicity testing is combined with bank-side biological monitoring for short-term effects and in-stream biological monitoring for longer-term effects, and further linked to bioaccumulation studies and physico-chemical water analyses. Such integration may not be common, but it does reflect the high value being placed on the aquatic/wetland ecosystems of the region being monitored. Obviously, high value regions that may be threatened by anthropogenic factors warrant greater attention than low value regions.

CLARKE (1993) considered the requirements for a monitoring system for addressing environmental concerns and came up with the following recommendation. Systems designed to monitor ecological change should be able to detect the presence of an environmental perturbation, assess the seriousness of the perturbation, identify the cause of the perturbation and provide the means of evaluating the extent of recovery after any remedial action is taken. Not surprisingly, CLARKE (1993) also concluded that it was unrealistic to expect that any one technique or approach could be used to perform these tasks and that an integrated approach incorporating a variety of techniques was needed. Unfortunately, all too often there is very little effective monitoring of wetlands using a single technique (see DUGAN & JONES

1993), let alone using a suite of integrated techniques as developed by HUMPHREY et al. (1990).

MONITORING TECHNIQUES

As already mentioned, a plethora of monitoring techniques exist and many are being used to monitor aquatic and wetland habitats around the world. Two of these are addressed below: remote sensing and biological monitoring. These were chosen as they represent techniques that have received a lot of attention in recent years and offer great potential for monitoring at the habitat, population and individual species level respectively.

Remote sensing

Background

Satellite imagery can be used to assess the status of particular features of wetlands (e.g. areal extent, vegetation and water coverage) and possibly even identify changes in land use that detrimentally affect wetlands. Through comparison with historical records, the extent of ecological change can be identified. In this instance, the baseline is provided by previously taken images and/or maps.
The use of satellite data (remote sensing) as an environmental monitoring tool commenced in 1972 with the launch of the US Landsat satellite. The latest Landsat satellite uses a Multi-Spectral Scanner (MSS) that covers green, red, and two very-near infra-red bands with an 80 m resolution; a Thematic Mapper (TM) covering blue, green, red, very-near infra-red (VNIR) and two short wave infra-red (SWIR) bands with a 30 m resolution and a thermal, infrared band with a 120 m resolution (DRURY 1990). Data are now also available from the French SPOT and Japanese MOS satellites with 20 m and 50 m resolution respectively in visible and VNIR bands. Satellite remote sensing has been used for monitoring wetlands and lakes in a number of parts of the world (e.g. NAKAYAMA 1993; YATES et al. 1993; MULLER et al. 1993). However, even with improvements in the detail and reliability of information derived from satellites, the accuracy and reliability may not match that from conventional aerial photography using manual photo-interpretation, such as that used in the USA National Wetlands Inventory Project (see WILEN 1990) and recommended for use in Australia by JOHNSTON & BARSON (1993).

Beneficial aspects

Improvements in the detail and reliability of information derived from satellites include advances in spatial and spectral resolution, geo-referencing and digital image processing techniques along with great strides in the integration of data through the use of Geographic Information Systems (GIS). In fact, the strength of satellite imagery lies in its ability to be integrated with other sources of data in a GIS and the development of digital terrain maps and models.
The main advantage of using satellite imagery for monitoring wetlands is the ease with which large and remote areas can be surveyed regularly. Furthermore, the Landsat archive contains data going back to 1972. However, in some parts of the world it is difficult to find cloud-free scenes; a problem encountered by NAKAYAMA (1993) when looking for historical imagery for a lake in tropical Malaysia. Eventually, suitable scenes were found in the archives and used as historical comparisons for assessing vegetation change around a wetland. NAKAYAMA (1993) also used satellite imagery to assess rates of degradation of mangroves in Thailand and identified the construction of shrimp farms as the major cause of the decrease in the area of mangroves.

Cloud cover is acknowledged as a major limitation to the use of satellite imagery. Recently, attempts have been made to utilise radar imagery to overcome this problem (MELACK et al. 1991; HESS et al. 1990) and thereby map extensive wetland systems such as those in the Amazon basin. The provision of historical records for extensive and even remote areas is sorely needed if trends in wetland loss and degradation are to be determined on a continental and global scale.

Of great interest to environmental managers is the use of satellites to monitor water quality in lakes and streams (MULLER et al. 1993; NAKAYAMA 1993; ALMANZA & MELACK 1985; KANDRATYEV & POZDNIAKOV 1992; GITELSON et al. 1993). Preliminary results indicate that it may be possible to survey the water quality in large numbers of waterbodies by linking the radiance of TM bands obtained from satellites to water quality parameters. YATES et al. (1993) have been attempting to use satellite imagery to monitor changes in the distribution of sediments in estuaries and thereby use this information to predict the likely consequences for shorebirds. Identification of the extent of water cover is relatively straightforward using remote-sensing data, except in forested wetlands (MULLER et al. 1993), although the use of synthetic aperture radar (SAR) could prove to be a suitable technique for measuring flooding beneath a vegetation canopy (MELACK et al. 1991; HESS & MELACK 1994).

Limits

MULLER et al. (1993) assessed the use of remote sensing data in river studies and came up with a number of limits to the use of such data and imagery that equally apply to wetlands. These include: the size of the area to be monitored with narrow channels or riparian zones often being too small compared to the pixel size; the acquisition of high-resolution data over large areas could become prohibitively expensive; data interpretation still relies on ground truthing or a good knowledge of the area under investigation; and the absence of reliable relationships between spectral radiances and land-water features limits the use of automatic interpretation of images.

For remote sensing to be more useful for wetland monitoring there is a need to relate the acquired data to ecological variables and to several scales. Ecologists need to define the key ecological variables at various scales that can be correlated with radiation characteristics of sensing devices and to define further environmental variables that can be more easily related to remote sensing data. Despite these limitations there is already demonstrable worth in using remote sensing techniques, although MULLER et al. (1993) point out that for rivers much of the work has been of a preliminary nature and few projects have devolved towards routine monitoring; this would also appear to be true for wetlands.

Biological monitoring

Techniques

Until recently, environmental monitoring in streams and lakes has concentrated on physico-chemical analyses to assess the presence of water-borne anthropogenic substances. This approach has a number of limitations, with the most important being the lack of information on the biological impact or consequences of the stressors being monitored. Biological monitoring techniques are designed to assess the impact of environmental disturbance on particular target organisms. Techniques for doing this are many and varied, including bioassays, indicator organisms (presence or absence), autecological or population studies, community structure or function, and bioaccumulation. The objective of these approaches is to assess the impact of stress on the organism or the ecosystem (CLARKE 1993). The use of a multiplicity of techniques provides a firmer basis for evaluating an ecological change.

A further set of techniques are grouped under the broad heading of biochemical and histopathological sub-lethal methods (CLARKE 1993). The underlying assumption of these tests is that the presence of environmental stress changes the normal biological responses of the organisms subject to the stress. These tests generally fall into biochemical, physiological, developmental, behavioural and genetic categories, and many of them have been developed for monitoring changes in water quality. As the majority of endpoints utilised in these tests measure specific responses to specific stressors they are particularly well suited to identifying causative agents for observed changes. However, a lack of response in a particular species to a given stressor does not mean that the ecosystem is not being affected. One technique that has been shown to be highly sensitive and which has considerable potential as a biomonitoring tool is the measure of deviations from perfect bilateral symmetry of morphological structures, referred to as fluctuating asymmetry (ZAKHAROV 1990, 1993; CLARKE 1993). Further research into these techniques is being conducted in a number of countries (see summary in ZAKHAROV & CLARKE 1993).

The choice of methods to be used in a biological monitoring programme depends largely on the nature of the problem. DOSTINE et al. (1993) point out that both short-term (e.g. resulting from "pulse" disturbances) and longer-term (cumulative) effects need to be considered. The monitoring programme also needs to be sensitive to effects resulting from increased concentrations in the water column and those arising from build-up in the sediments. For either short-term or longer-term effects, the programme must also be able to provide both early detection of change (impact) and an assessment of the ecological significance of the change. Bioaccumulation by long-lived organisms, such as mussels and fish, have often been used to detect long-term effects by establishing a baseline concentration of chemical elements and comparing to trends over time, although BIGNERT et al. (1993) point out that establishing such trends is very dependent on the time-span of the study and the frequency of sampling.

Longer-term techniques

For longer-term detection, studies of natural communities and populations have often been used along with chemical monitoring of the biota (e.g. DOSTINE et al. 1993: KARR 1987; JEAN & FRUGET 1993; NORRIS & GEORGES 1993). Ecological insights from studies of the structure and dynamics of populations, communities and ecosystems do not necessarily provide prompt detection of ecological change. However when coupled with appropriate design and analysis, they can provide direct evidence of the extent to which agreed management objectives are being achieved. The underlying assumption of these approaches is that environmental changes will lead to changes in the abundance of a particular species, species distribution or number of species.

The presence or absence of indicator species is a relatively simple form of biological monitoring, although the choice of organism for specific situations can be difficult. KUSHLAN (1993) considers that the trajectory of change for a bioindicator should reveal an underlying trend in the same direction as the functions being monitored. Furthermore, KUSHLAN (1993) points out that a bioindicator in a wetland can be considered a dependent variable and the environmental factors that control wetland functions are the independent variables. When monitoring, changes in the dependent variable are being measured, leaving undetermined which of the independent variables in the multivariate system has changed. Thus, care must be taken in interpreting indicator responses as in many cases, the cause is unclear. Changes in the bioindicator can be used to infer hypotheses as to the causes if the biology of the indicator is well enough understood. Overall, bioindicators are valuable as they are integrative, relatively inexpensive and functionally pertinent. KUSHLAN (1993) also points out that bioindicators can reflect exposure to a stressor and/or reflect impairment by a stressor.

Where there is no a priori reason for selecting indicator species, consideration of the entire community is appropriate. This is essential if concern for biodiversity is the primary goal of the monitoring programme. The most common community methods have been those using macro-invertebrates to assess changes in water quality (see MAHER & NORRIS 1990; NORRIS & GEORGES 1993). DOSTINE et al. (1993) considers that macro-invertebrates are suitable for community studies as the communities are generally diverse and abundant, their taxonomy is often reasonably well known, sampling methods are well developed, they are relatively sedentary and respond rapidly to changes in water quality. Fish have also been used for community studies (e.g. BIGNERT et al. 1993; BISHOP & PIDGEON 1994).

Programme design

The design of a biological monitoring programme can be difficult to establish, particularly in streams. DOSTINE et al. (1993) and HUMPHREY et al. (1994) have considered the difficulties of sampling in streams where upstream processes may affect downstream results and hence the notion of an upstream control site independent of sites downstream is problematic. In monitoring exercises designed to detect effects arising from a point source, a common design is to use an upstream undisturbed site as the control and areas downstream as experimental sites. Replicate samples taken from each site are spatially segregated but do not constitute real replicates (pseudo-replication); if differences between the sites exist, it is not possible to implicate the treatment (point pollution source) as the causal factor. Designs using a form of temporal replication have been proposed as a solution to the problem of testing for the effects of an unreplicated impact (see discussion and background in HUMPHREY et al. 1990, 1994). Thus, the BACIP design (Before, After, Control, Impact, Paired differences) where samples are collected simultaneously from single impact and control sites before and after the impact has occurred has been developed. This sampling approach and the statistical analysis assumes that the observed differences in a time series are independent. However, even this approach is criticised and UNDERWOOD (1991) argues that multiple control sites are essential, especially if the inference power of the analyses are to be extended.

DOSTINE et al. (1993) also consider the number of replicates necessary to provide sufficiently high power (i.e. high probability of correctly detecting an effect) of the sampling approach. Power curves describe the relationship between effect size and the sample size required to detect an effect for a given level of power. Thus, the smaller the effect the larger the number of samples required to detect this at a specific probability. Choosing the level of probability immediately raises the question of establishing what is an acceptable level of change; a question that extends beyond the realms of the ecologist collecting the samples to the realms of those responsible for setting environmental standards. Thus, the design of a sampling programme needs to not only consider biological and statistical factors, but also the societal attitude towards protecting a site. Hence, whilst there is increasing realisation that the need for a monitoring programme can be dependent on societal attitudes it is also essential to determine societal expectation or tolerance of the extent of change that can be detected by the programme: determining the ecological significance of an environmental change may well be easier than determining societal tolerance of this change.

Therefore, monitoring for ecological change cannot be realistically undertaken without involving societal attitudes at all stages of the planning process. For this to occur it may even be necessary to expend resources on public awareness and education programmes before undertaking the monitoring programme! The importance of such training for wetland conservation was recognised for Central and Eastern Europe (FINLAYSON & DENNY 1992). Now it is essential that such steps are taken if effective programmes for monitoring ecological change are to be designed, implemented and **utilised** to prevent further loss and degradation of wetlands in this part of Europe.

SUMMARY

Monitoring of ecological change in wetlands has been receiving more and more attention in recent years with new techniques being developed and others modified. In some instances, a great deal of research effort has been directed towards developing appropriate techniques and statistically valid means of sampling and analysing the data. The use of satellite imagery and biological monitoring techniques are two areas that have received such attention, with the achievement of impressive advances. However, when designing a programme for monitoring ecological change, the choice of technique is only one aspect of the process. It is essential that the entire planning process is subject to a rigorous analysis and that the objectives are clearly stated and understood. It is also essential that data analysis and reporting is planned in a manner that enables management decisions to be taken and implemented in a timely manner. For this to be achieved, effort is required to ensure that the techniques actually supply data that can be used to address the management questions. It may therefore be necessary to establish hypotheses and test them before embarking on a full scale programme. Similarly, the statistical validity of the sampling methods may need to be tested. Above all, it needs to be recognised that all programmes should be regularly and critically reviewed.

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