

MedWet

# Monitoring Mediterranean Wetlands

A methodological guide

Edited by Pere Tomàs Vives



**WETLANDS**  
INTERNATIONAL

**ICN**   
Instituto da Conservação da Natureza

## **The MedWet action**

The Mediterranean basin is rich in wetlands of great ecological, social and economic value. Yet these important natural assets have been considerably degraded or destroyed, mainly during the 20th Century. To stop and reverse this loss, and to ensure the wise use of wetlands throughout the Mediterranean, a concerted long-term collaborative action has been initiated under the name of MedWet.

A three year preparatory project was launched in late 1992 by the European Commission, the Ramsar Convention on Wetlands of International Importance, the governments of France, Italy, Spain, Greece and Portugal, the World Wide Fund for Nature, Wetlands International (former IWRB), and the Station Biologique de la Tour du Valat.

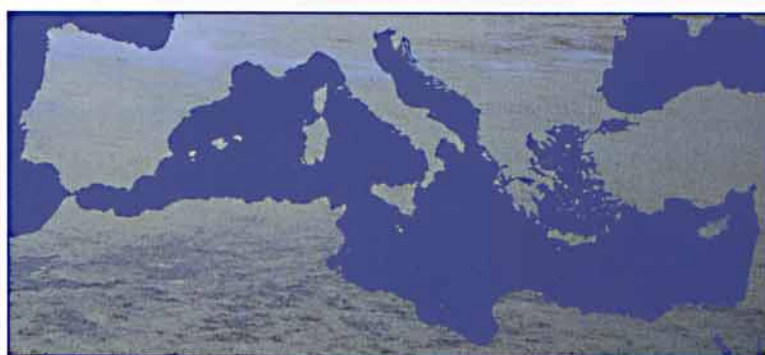
This project focuses on that part of the Mediterranean included within the European Union, with pilot activities in other countries such as Morocco and Tunisia. Two thirds of the funds are provided by the European Union under the ACNAT programme and the remainder by the other partners.

The concept of MedWet and its importance for the wise use of Mediterranean wetlands was unanimously endorsed by the Kushiro Conference of the Contracting Parties to the Ramsar Convention in June 1993.

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## A methodological guide



Edited by  
Pere Tomàs Vives

*Scientific editors*  
Nick Riddiford, Patrick Grillas, Max Finlayson, Nathalie Hecker  
Rui Rufino, Barrie Goldsmith

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Cover photograph: Permanent pond in a mountain stream of the Serra de Tramuntana (Mallorca) habitat of the Mallorcan midwife toad *Alytes muletensis* (in the foreground) (Biel Sewrvera). Inset: The endemic Mallorcan midwife toad (Biel Sewrvera).

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# Foreword

The rapid loss and degradation of Mediterranean wetlands has demanded urgent and concerted actions. In recognition of this, the 1991 conference on Managing Mediterranean Wetlands and their Birds (Grado, Italy) led to the launch of the MedWet Initiative. A first three year preparatory action under MedWet has prepared and tested the necessary tools for a long-term pan-Mediterranean wetland conservation initiative.

This Guide documents the methodologies developed under the first phase of MedWet for monitoring Mediterranean wetlands. It forms one output of the MedWet sub-project on Inventory and Monitoring, which has been carried out by Wetlands International (formerly IWRB) and the Instituto da Conservação da Natureza, Portugal. Other key outputs of this sub-project include a review of The Status of Wetland Inventories in the Mediterranean Region, and A Reference Manual for undertaking Mediterranean wetland inventories, including a comprehensive suite of inventory tools.

In any strategic approach to the conservation of wetlands, monitoring plays a crucial role in evaluating the success of previous management actions, and in determining what additional actions

are necessary to achieve the desired objective. Monitoring allows the detection of ecological changes and their causes, so that corrective actions can be undertaken.

This Guide provides a methodological framework to assist in the planning of monitoring programmes for Mediterranean wetlands. Because of the complexity and diversity of wetland systems, the Guide does not provide a recipe book for establishing surveillance programmes, but instead assists the user to plan monitoring programmes which meet specific objectives.

The MedWet work on monitoring has broken new ground, both for the Mediterranean region and for other parts of the world. The development of the Guide has already contributed to the development of guidelines for monitoring change in the ecological character of wetlands under the Ramsar Convention and we hope that it will also set a standard for work in wetlands and other habitats at sites covered, for example, by the European Union's Natura 2000 network.

Michael Moser  
*Wetlands International*

António Teixeira  
*ICN, Portugal*

# Acknowledgements

People from different countries and backgrounds have collaborated in the preparation and production of this methodological guide. I want to acknowledge first the contribution of the Expert Advisory Group to the MedWet sub-project on Inventory and Monitoring, formed by wetland scientists and conservationists from different countries. The Advisory Group met twice in Portugal (1993) and Tunisia (1994) to define the objectives and the basis for this Methodological Guide, and to provide guidelines for its development. I also wish to thank the organisers of the meetings: the Instituto da Conservação da Natureza, Portugal, and the Direction Générale des Forêts, Tunisia.

In summer 1994, an editorial committee was created, comprising the MedWet staff of Wetlands International and ICN and some of the scientists who participated in the second meeting. In 1995 and 1996, pilot studies were established at five Mediterranean wetlands – Sado Estuary (Portugal), S'Albufera de Mallorca (Spain), Lake Kerkini (Greece), Étang de l'Or (France) and Aiguamolls de l'Empordà (Spain) – to test the method proposed in the guide. The scientific and field teams at these sites (see list of contributors) were deeply involved in the testing and preparation of detailed reports that are included in this Guide as case studies.

The process of preparation, editing and revision of the texts has not been easy due to the dispersal of the authors and editors, and especially because of the short time available. I wish to express here

my gratitude to all the contributors (see list) for their interest and commitment which have permitted the production of this document in such a short time. Special thanks to Nick Riddiford who has worked very hard in the scientific editing of the document and who has given a fine English style to the final text.

I wish also to thank Joan Mayol Serra and the staff of the Parc Natural de S'Albufera for their help, in particular to Gabriel Perelló Coll – who helped a lot in the organisation of the meeting – and to Muro Local Council for allowing us to use their facilities during the workshop. A few other people provided very useful comments to the drafts: Mike Moser from Wetlands International, Mike Wood and Chris Donnelly from the Earthwatch Europe Project S'Albufera team. Fernando Tortella provided several references for the bibliography. Thanks also to the people who have kindly donated photographs for inclusion in this Guide.

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Pere Tomàs Vives  
*Coordinator and Editor, Wetlands International*  
May 1996

# Contributors

António Bruxelles  
ICN  
Instituto da Conservação da  
Natureza  
Rua Filipe Folque, 46 5°  
1050 Lisboa  
Portugal

M. Helena Costa  
Universidade Nova de Lisboa  
Fac. Ciências e Tecnologia  
Dept. de Ciências e Engenharia  
do Ambiente  
Lisboa  
Portugal

Tasos Dimalaxis  
Greek Biotope/Wetland Centre  
(EKBY)  
14th Km Thessaloniki-Mihaniona  
57001 Thermi  
Macedonia  
Greece

C. Max Finlayson  
Environmental Research Institute  
of the Supervising Scientist  
Locked Bag 2  
Jabiru  
0886 Northern Territory  
Australia

Barrie Goldsmith  
Department of Biology  
University College London  
Gower Street  
London  
WC1E 6BT  
United Kingdom

Patrick Grillas  
Station Biologique de la Tour du  
Valat  
Le Sambuc  
13200 Arles  
France

Nathalie Hecker  
MedWet/Wetlands International  
Station Biologique de la Tour du  
Valat  
Le Sambuc  
13200 Arles  
France

George E. Hollis  
Wetland Research Unit  
Department of Geography  
University College London  
26 Bedford Way  
London  
WC1H 0AP  
United Kingdom

Antonis Mantzavelas  
Greek Biotope/Wetland Centre  
(EKBY)  
14th Km Thessaloniki-Mihaniona  
57001 - Thermi  
Macedonia  
Greece

Joan Mayol Serra  
Parc Natural de S'Albufera de  
Mallorca  
Conselleria d'Agricultura i Pesca  
Foners, 10  
07006 Palma de Mallorca  
Illes Balears  
Spain

Aura Penloup  
Station Biologique de la Tour du  
Valat  
Le Sambuc  
13200 Arles  
France

Nick Riddiford  
Fair Isle  
Shetland  
ZE2 9JU  
United Kingdom

Sergio Romero de Tejada  
Parc Natural dels Aiguamolls de  
l'Empordà  
El Cortalet  
17486 Castelló d'Empúries  
Girona  
Spain

Carmen Rosado  
ICN  
Instituto da Conservação da  
Natureza  
Rua Filipe Folque, 46 5°  
1050 Lisboa  
Portugal

Rui Rufino  
MedWet/ICN  
Instituto da Conservação da  
Natureza  
CEMPA  
Rua Filipe Folque, 46 5°  
1050 Lisboa  
Portugal

Pere Tomàs Vives  
MedWet/Wetlands International  
Avda. del Cid, 76 2°  
07198 Palma de Mallorca  
Illes Balears  
Spain

# 1 Introduction



**Pere Tomàs Vives**

*Wetlands throughout the Mediterranean region have been lost or degraded at an alarming rate, most notably during the twentieth century. The serious extent of this loss and degradation was documented at a major conference on Mediterranean wetlands held in Grado (Italy) in 1991 (see Finlayson et al. 1992). The Grado Declaration adopted by the conference requests the adoption of the following goal: to stop and reverse the loss and degradation of Mediterranean wetlands (Anonymous 1992). To assess progress towards the Grado goal it is necessary to detect any changes, actual or potential, occurring in wetlands and to measure their magnitude as well as their causes and consequences.*

*On the other hand, the Convention on Wetlands of International Importance especially as Waterfowl Habitat, known as the Ramsar Convention, states (article 3.2) that "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 has changed, is changing or is likely to change as a result of technological developments, pollution, or other human interference". Furthermore, the Sixth Conference of the Contracting Parties held in Brisbane, Australia, in March 1996, adopted a set of guidelines for interpreting change in ecological character, which had been developed by the Convention's Scientific and Technical Review Panel (STRP).*

*Therefore, systems for monitoring changes in wetlands are required, monitoring being the systematic collection of information over time in order to ascertain the extent of compliance with a predetermined standard (baseline).*

*Wetlands are complex ecosystems for which predictive models of their functioning are rare or do not exist. On the other hand, wetlands are not only affected by activities occurring on-site, but they are very much influenced by activities or events occurring in their catchment areas and at a global scale. It is often difficult to ascertain and evaluate the ecological effects that distant activities may have on a wetland. Nevertheless, consideration of what happens in the catchment area is essential to try to understand what happens in the wetland.*

*Monitoring wetlands is therefore a complex subject that has to be carefully planned following a methodical approach in order to be effective. When planning a monitoring programme, different factors have to be considered: the objectives of monitoring need to be defined based on the type of change and its scale, both in time and space, and on the type of wetland. The resources available, both human and financial, and the existing constraints must be considered when choosing the parameters and techniques to use.*



## 1.1 Guide to monitoring Mediterranean wetlands

This methodological guide is the product of a collaboration between wetland scientists and managers from different countries, from both the Mediterranean region and outside. A workshop was organised in Mallorca, Spain, in January 1996 to bring together most of these scientists and managers in order to review the method proposed.

The objective of this publication is to provide guidance for designing programmes which monitor ecological change in Mediterranean wetlands. It is presented as a methodological framework that describes the steps involved in planning a monitoring programme, and includes detailed guidelines for the selection of appropriate indicators to monitor specific problems.

Pilot studies have been carried out at a number of wetland sites in order to complement the methodological framework and guidelines with

practical aspects, and detailed bibliographic research has been undertaken in order to identify publications and documents relevant for monitoring wetlands.

## 1.2 Use of this methodological guide

The guide is addressed to the people responsible for Mediterranean wetlands, in particular wetland managers, planners and scientists. Ideally, any monitoring programme should form part of a management plan, so that the actions decided as a result of monitoring are implemented in the context of an existing response system. However, this is not always the case in Mediterranean wetlands; firstly, many of them are not protected or managed for conservation; secondly, many protected wetlands do not yet have a written management plan or they are not managed in an organised manner.

Given the great diversity of Mediterranean wetlands, the diverse technical backgrounds of

**Plate 1.1** Wetlands in the Mediterranean region are being lost or degraded due to many factors: among them tourist development, construction of leisure facilities and road building. (Pere Tomàs Vives)





the potential users, and the variety of resources and information available, it is not feasible to cover all possible cases in this document. Therefore, this guide should not be seen as a recipe book, with predetermined instructions for monitoring any particular type of issue in any particular type of wetland. Decisions on how to apply the framework and to select the indicators rely on the user having a good knowledge of the site.

### 1.3 Contents of the guide

The contents follow a logical sequence which corresponds to the process of planning a monitoring programme. Chapter 2 presents an overview of the types and causes of ecological change in Mediterranean wetlands. This should help to identify the actual or potential changes occurring at a particular site and try to recognise their causes. Six types of change are presented: changes in wetland area, in water regime, in water quality, exploitation of wetland products, introduction of alien species, and changes due to management and restoration actions.

In chapter 3, the methodological framework for planning a monitoring programme is developed with some examples to illustrate its application. This framework consists of a series of steps, in a logical sequence, which can be used for designing monitoring programmes according to the particular circumstances and needs of a wetland site. This framework has been proposed by the Ramsar Convention's STRP to assist the Contracting Parties in designing effective monitoring programmes.

Chapter 4 provides guidance in the process of selecting indicators used to monitor specific types

of ecological change in Mediterranean wetlands. It also gives indications of the techniques that can be used to measure the indicators selected.

This is presented again, in a structured and systematic format (as tables), in chapter 5 to help the user identify the appropriate indicators and techniques. The tables also provide bibliographic references where the techniques are described.

Chapter 6 is a detailed bibliographic compilation of literature pertaining to monitoring and the techniques which are applicable to the choice and measurement of indicators.

Five case studies are described in chapter 7, each presenting the application of the planning framework to the specific situation of certain wetlands in different Mediterranean countries. The case studies illustrate how the process of planning a monitoring programme can be implemented in reality, and reveal practical aspects which must be considered in this process. For some of the pilot sites (e.g. Aiguamolls de l'Empordà) the test has permitted initiation of the monitoring programme described, while for others it has allowed evaluation and review of existing monitoring (e.g. S'Albufera de Mallorca).

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## 2 Ecological change in Mediterranean wetlands

G.E. Hollis and C.M. Finlayson



### ABSTRACT

*Mediterranean wetlands have been destroyed and degraded historically and the processes continue today. These wetlands, through their functions (e.g. groundwater discharge, flood control, storm protection, wildlife habitat etc.), products (e.g. fisheries, grazing, water supply etc.) and attributes (e.g. biological diversity) are valuable, normally in economic terms, to human society. Ecological change can be natural (e.g. vegetation succession, sedimentation etc.), or induced by human action some of which can be positive through active site management and wetland restoration projects. Examples of adverse ecological changes through human agency in Mediterranean wetlands are very numerous. The major types of processes leading to ecological change are:*

- *changes in wetland area*
- *changes in the water regime*
- *changes in the water quality*
- *unsustainable exploitation of wetland products*
- *introduction of alien species*
- *management, neglect and restoration*

*The underlying factors responsible for ecological changes are social, economic and political and are expressed through policy and institutional elements. The apparent and visible causes of adverse change in wetlands include:*

- *agricultural intensification*
- *urbanisation and industrialisation*
- *tourist development*
- *expanding fisheries and aquaculture projects*
- *hunting activities*

*In terms of monitoring, it is usually insufficient to assess only the actual changes occurring in the wetlands. The processes in society leading to these normally adverse changes are, by then, already under way to such an extent that they may be unstoppable. A comprehensive wetland monitoring programme therefore has to have elements in the wetlands but other components in the offices of development agencies and in the debating chambers where public policy is formulated. The management of global environmental change has to take place at international level, but local ecological monitoring may reveal opportunities for site specific mitigation and management.*



## 2.1 Introduction

Wetlands in the Mediterranean region include estuaries, river deltas, coastal lagoons, lakes, marshes and oases, salt marshes, natural and artificial salines and reservoirs (Pearce & Crivelli 1994). These habitats provide many benefits for humans both locally and further afield, but over most of this century many of them have been degraded and lost with a much more limited number of examples demonstrating the positive impact that human intervention can have on wetland functioning (see, for example, Finlayson *et al.* 1992, Morgan 1982, Montes & Bifani 1991, Mermet 1991, Psilovikos 1992, Papayannis 1992a). These processes continue and so a monitoring system is central to policy review and sound environmental management. Even some of the most valuable internationally important wetlands in the Mediterranean have undergone, are undergoing or will undergo adverse changes in ecological character (Ramsar Bureau 1990). This has been revealed by governmental monitoring procedures and addressed by the Ramsar Monitoring Procedure (renamed Management Guidance Procedure in March 1996) which links advice on ameliorative strategies to identification of problems. Tablas de Daimiel and Doñana in Spain, Lake Oubeira in Algeria, Stagno di Molentargius and Stagno di Santa Gilla in Italy, Lake Ichkeul in Tunisia, Lakes Bardawil and

Burullus in Egypt, and all eleven Greek Ramsar sites feature on the Montreux Record of wetlands suffering change of ecological character (Ramsar Bureau 1993a). The loss and degradation of so many valuable wetland functions necessitates a more extensive and intensive monitoring effort so that policy formulation can be appropriately informed.

This chapter, setting the scene on wetland monitoring, considers first the values we derive from these wetlands. It then discusses the nature of ecological change in wetlands and overviews the social, economic and political origins of such ecological change. Both the underlying (such as socio-economic policies and practices) and apparent causes of wetland loss and degradation (e.g. agricultural intensification and tourist developments) are described. It is found that there is a need for monitoring of individual wetland sites and their ecosystem components; the processes that bring change, usually adverse, to these wetlands; and the policies and plans that lie behind the relationship of humans to Mediterranean wetlands.

## 2.2 Wetland values

Wetlands, transitional between terrestrial and fully aquatic habitats, are composed of physical, biological and chemical components such as water,

Plate 2.1 Wetlands provide habitat for wildlife: heron roost in the Guadalquivir river, as it flows past the ancient mosque of Córdoba, Spain. (Pere Tomàs Vives)





TABLE 2.1 Wetland values associated with wetland types in the Mediterranean (after Dugan 1990; and Skinner &amp; Zalewski 1995).

WETLAND TYPES	Estuaries	Aquatic beds	Deltas	Coastal lagoons	Floodplains	Lakes	Seasonally flooded freshwater marshes	Saline pans and marshes	Springs and oases	Reservoirs	Salt works lagoons	Created freshwater habitat (irrigation channels, rice paddies, fish ponds, etc.)
<b>VALUES</b>												
<b>Functions</b>												
Groundwater recharge	○	○	□	○	■	■	□	○	○	□	○	□
Groundwater discharge	□	○	□	□	□	□	□	□	■	○	○	□
Flood control	○	○	□	○	■	■	■	□	○	■	○	□
Sediment/toxicant retention	■	○	■	□	■	■	■	□	○	■	○	□
Nutrient retention	■	○	■	□	■	■	■	○	○	■	○	○
Shoreline stabilisation	■	□	■	■	□	○	○	○	○	○	□	○
Storm protection/windbreak	■	○	■	■	○	○	○	○	○	○	□	○
Water transport	■	○	□	■	□	□	○	○	○	○	○	○
Food chain support	■	■	■	■	■	□	■	□	■	□	□	□
Wildlife habitat	■	■	■	■	■	■	■	□	□	□	■	□
Active recreation	■	■	■	■	□	■	■	□	□	□	○	□
<b>Products</b>												
Wildlife resources	■	■	■	■	(■)	■	(■)	□	□	□	○	□
Fisheries	■	■	■	■	(■)	■	■	○	○	□	○	□
Forage resources	■	○	■	○	■	○	■	□	□	○	○	□
Agricultural resources	□	○	■	○	■	○	■	○	□	■	○	■
Water supply	○	○	■	○	■	■	□	○	■	■	○	□
Forest resources	○	○	□	○	(■)	○	□	○	○	○	○	○
<b>Attributes</b>												
Biological diversity	■	■	■	□	■	□	■	■	□	□	□	□
Uniqueness to culture/heritage	■	□	■	■	□	□	■	■	■	○	□	○
<b>Key:</b> ○ = absent or exceptional    □ = present    ■ = common and important of that wetland type ( ) = largely degraded in the Mediterranean												

soil, plants and animal species. Processes among and within these components allow a wetland to perform certain functions such as flood control and storm protection, and generate products such as wildlife, fisheries and forest resources. In addition, there are ecosystem scale attributes such as biological diversity and cultural uniqueness/heritage (Dugan 1990). All wetlands have a number of these valuable functions, products and attributes that often go unrecognised until they are degraded or lost (Adamus & Stockwell 1983; Hollis *et al.* 1988; Skinner & Zalewski 1995). Tampering with the processes that support these functions, products and attributes, especially the hydrological regime,

can quickly degrade the value of the wetland. Once a wetland has been degraded or lost it can be extremely expensive to restore.

Across the Mediterranean, the wetland functions, products and attributes that give wetlands values and benefits have been severely degraded. However, not all functions, products and attributes are equally important in all types of wetlands; Table 2.1 depicts key values generally associated with the major wetland types found in the Mediterranean. Table 2.2 gives a list of wetland functions along with Mediterranean examples where they are still partly or even wholly intact and where they have been degraded or lost.

**TABLE 2.2** *Examples of Mediterranean wetlands where key functions have been retained and where they have been lost.*

Wetland function	Function retained	Function lost or seriously diminished
Groundwater recharge	Sebkhet Kelbia, Tunisia Megali Prespa, Greece	Garaet el Haouaria, Tunisia R. Acheloos Floodplain, Greece
Groundwater discharge	Merja Zerga, Morocco Göksu Delta, Turkey	Tablas de Daimiel, Spain Phasouri Marsh, Cyprus Parts of La Vera, Doñana, Spain Azraq Oasis, Jordan
Flood control	Lac Fetzara, Algeria Lakes Volvi and Langada, Greece Sidi Saad Reservoir, Tunisia	Po Floodplain and Delta, Italy River Strymon Floodplain, Greece Garaet Mabtuha, Tunisia Lower Mondego Valley, Portugal
Sediment/toxicant retention	Lake Hula, Israel Lake Kerkini, Greece Odiel Marshes, Spain	Kizilirmak Delta, Turkey River Júcar, Valencia, Spain
Nutrient retention	Mekhada Marsh, Annaba, Algeria S'Albufera de Mallorca, Spain	Axios Delta, Greece
Shoreline stabilisation	Languedoc-Roussillon Lagoons, France	Nile Delta, Egypt
Water transport	Grado-Marano Lagoon, Italy River Rhône, France Lac de Bizerte, Tunisia	Utique, Tunisia
Food chain support	Kneiss Islands Mudflats, Tunisia Akgol Lagoon, Turkey	Stagno di Molentargius, Sardinia, Italy
Wildlife habitat	Lac Tonga, Algeria Mikri Prespa, Greece Tejo Estuary, Portugal	Ichkeul, Tunisia Lake Bardawil, Egypt
Active recreation	Camargue, France Lake Skadar, Montenegro	Stagno di Santa Gila, Sardinia, Italy

Mitsch & Gosselink (1993) refer to wetlands both as "the kidneys of the landscape" and as "biological supermarkets" because of the extensive food chain and rich biodiversity they support. The financial valuation of wetland functions and products is advancing rapidly (e.g. Barbier 1989). The establishment of the Ichkeul National Park in northern Tunisia, its designation as a World Heritage Site, a Biosphere Reserve and Ramsar site, was based primarily on non-use, existence values of its wetlands. However, the lake and marshes are valuable for livestock grazing on the marshes, fisheries in the lake, tourism, the role of rivers in groundwater recharge and the treatment of sewage and purification of water by the marshes. Thomas *et al.* (1991) have shown that the economic value of releasing water from dams on the various rivers feeding the wetlands outweighs the benefits of using the water in agricultural irrigation. The sewage treatment function alone was valued at over US\$170,000 per year, since this would be the cost of an industrial sewage treatment works, whilst the

lake fisheries were valued at US\$650,000 per year. Obviously, a part of most wetland monitoring programmes needs to have a component devoted to economic values and financial data.

The value of all wetlands is not equal, but given the historical loss and degradation of Mediterranean wetlands the value of remaining wetlands has been enhanced. Nowadays, all Mediterranean wetlands are considered valuable whilst acknowledging that many may need remedial attention to regain their full value. The monitoring of the overall stock of a nation's wetlands is needed if the relative value of particular wetlands is to be determined with any certainty.

## 2.3 Types of ecological change

The Ramsar Convention states (article 3.2) that "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 has changed, is changing or is likely to change as a result of technological developments, pollution, or other human interference." Clearly therefore, it is essential that there are monitoring procedures at each Ramsar site to establish if there is ecological change and, if so, in what direction it is trending. The Convention defined "ecological character" and "change in ecological character" at the Sixth Conference of Contracting Parties in March 1996. These are given below:

**Ecological character** is the structure and inter-relationships between the biological, chemical, and physical components of the wetland. These derive from the interactions of individual processes, functions, attributes and values of the ecosystem(s).

**Change in ecological character of a wetland** is the impairment or imbalance in any of those processes and functions which maintain the wetland and its products, attributes and values.

The resolution adopted at the Sixth Ramsar Conference indicates that "Change in ecological character of a site is interpreted as meaning adverse change, in line with the context of article 3.2 and Recommendation 4.8 which established the Montreux Record." It also recognizes that "wetland restoration and/or rehabilitation programmes may lead to favourable human-induced changes in ecological character."

IWRB (1993) concluded that ecological change can take place in entirely natural wetland systems through, for instance, vegetation succession, sedimentation and accumulation of organic matter. However, human-induced ecological change, and especially that which has taken place in the last 30 years, is a much more significant process for the world's wetlands (IWRB 1993). This human-induced change can be negative, where wetland ecosystems are degraded or destroyed, or positive where conservation management programmes are successful. A positive change of ecological character also occurs when fully functioning wetland conditions are returned to a "lost" wetland through a restoration programme.

There needs to be monitoring of natural ecological change in wetlands so that its rate and direction can be determined as a "background reading" against

which to judge changes in wetlands affected, positively or negatively, by human activity. A fundamental part of any management programme is monitoring (Nature Conservancy Council 1987, Wood & Warren 1978) so as to provide feedback into the management cycle over time. Similarly, the importance of monitoring for wetland restoration schemes has been emphasised as a means to make adjustment to the implementation of the scheme, to ensure the longevity of the project through active management, and to contribute to scientific knowledge of habitat restoration (Kusler & Kentula 1990).

#### Main categories of processes producing ecological change

- changes in wetland area,
- changes in the water regime,
- changes in the water quality,
- unsustainable exploitation of wetland products,
- introduction of alien species,
- management, neglect and restoration.

### 2.3.1 Changes in wetland area

Wetland area can be lost by numerous processes. Filling of the wetland creates reclaimed land that can be developed. Coastal wetlands in the Mediterranean are particularly vulnerable to tourist developments of this type. Wetlands may be drained completely to try to eradicate mosquito and other pests and partial drainage may be undertaken to transform a wetland into agricultural land. The construction of embankments and wetland filling is often undertaken for the construction of roads or other lines of communication. This can both destroy wetland area directly and cause such disruption to the water regime that the wetland is effectively destroyed as a secondary effect. Waste disposal and rubbish dumping is also prevalent in wetlands.

The Lake of Tunis has been gradually reduced by urban encroachment, road, rail and shipping routes, port expansion and industrial development. During the 1980s about 35% of the northern part of the lake was reclaimed by filling and rubbish disposal. This provided large areas of land for building a new centre for the city; lakeside locations for prestige buildings; and a reduced lake volume which could, it was hoped, be more effectively turned over by the



**Plate 2.2** Infilling and reclamation are important causes of wetland loss in the Mediterranean region. Can Cullerassa, Mallorca. (Pere Tomàs Vives)

limited Mediterranean tides of the area (Zaouali 1983). Part of the Santoña marshes in northern Spain were similarly being filled for routeways and industrial development until the intervention of the European Commission.

Natural and diverse wetland functions can be lost even when wetland conditions remain. At the Amvrakikos Gulf in western Greece a series of intensive fish farms have been built with concrete pools, and several extensive aquaculture ponds have been created by embanking large areas of periodically flooded brackish water marsh (Papayannis 1992b).

In Algeria, the Ramsar site at Lac Tonga was partially desiccated by the pulling down of an embankment which retained water in the lake. Nearby, the edges of the extensive Mekhada marsh are being systematically drained to convert it into arable land (Stevenson *et al.* 1989). In Turkey, the straightening and embanking of the Kizilirmak and Göksu rivers where they flow through their deltas has reduced the area of riverine habitat, simplified the remaining river habitat and lowered the river bed so draining groundwater fed wetlands alongside the river (Hollis 1994).

### **2.3.2. Changes in the water regime**

The water regime is one of the driving forces in wetlands and helps determine the nature of the substratum. The crucial hydrological variables are water level, water balance, turnover rate and extreme conditions.

#### **Changes in the catchment of the wetland**

Water exploitation in the catchment upstream of a wetland can have serious repercussions on the ecological character of wetlands downstream and remote from the hydraulic works. Dams, inter-basin transfers, water abstraction and over-pumping of groundwater are common problems. Irrigation is widely considered to be the major consumptive use of water in the Mediterranean.

The Tunisian National Water Resources Plan envisages six dams on the rivers feeding the 126 km<sup>2</sup> Ichkeul National Park. This wetland had a lake which, before the dams, was high and fresh in winter with flooding on the surrounding marsh. The two largest dams divert water for potable supplies and irrigation whilst the smaller dams feed local



TABLE 2.3 Types of ecological change in wetlands with some of the indicative processes and Mediterranean examples.

Type of ecological change	Process bringing ecological change (NOT an exhaustive list)	Mediterranean example
Changes in wetland area	infilling: – urbanisation – industry road construction conversion for agriculture waste disposal	Lake of Tunis, Tunisia Eastern Camargue, Port Saint Louis, France Santoña, Spain Po Delta, Italy Messolonghi, Greece
Changes in the water regime of the catchment	dams: – inter-basin transfer – hydro-power  – irrigation  – reservoir evaporation – sediment trapping river abstraction groundwater abstraction	Garaet El Ichkeul, Tunisia Ebre Delta, Spain Tejo river, Portugal La Vera, Doñana, Spain Mondego flood plain, Portugal Acheloos Delta, Greece Rhône Delta and Camargue, France Axios Delta, Greece Tablas de Daimiel, Spain
Changes in the water regime of the wetland	drainage Lake Karla, Greece channelization land reclamation and polderisation  embankments water abstraction irrigation dredging navigation channels	Kizilirmak Delta, Turkey Camargue, France Ria de Aveiro, Portugal Lake Vistonis, Greece Lac Oubeira, Algeria Akgol Lagoon, Göksu Delta, Turkey Lac de Bizerte, Tunisia
Changes in water quality	sewage discharges industrial discharges aquaculture effluent nutrient runoff from agriculture  pesticide and herbicide runoff surface water salinisation groundwater salinisation changes to catchment land use: – deforestation – erosion and siltation change to link to the sea: – anti-salt barrage – opening lagoon mouths	Sebkhet Sedjoui, Tunisia Stagno di Cagliari, Sardinia, Italy Amvrakikos Gulf, Greece Valle Santa, Italy Sado Estuary, Portugal Doñana, Spain Sidi Salem Reservoir, Tunisia Cap Bon and Garaet El Haouaria, Tunisia  Mekhada Marsh, Algeria Merja Zerga, Morocco  Lake Mitricou, Greece Salses-Leucate Lagoon, Roussillon, France
Unsustainable exploitation of wetland products	over-fishing  over-hunting over-grazing excessive mineral extraction	Lake Burullus, Egypt Sto. André Lagoon, Portugal Biguglia Lagoon, Corsica, France Biviere di Gela, Italy Göksu River, Turkey
Introduction of alien species	alien plants alien fish alien birds	<i>Eucalyptus</i> , Odiel Marshes, Spain Goldfish <i>Carassius auratus</i> , Mikri Prespa, Greece Ruddy duck <i>Oxyura jamaicensis</i> , Spain
Management, neglect and restoration	restoration of open waters, control of vegetation, by: – burning – grazing – dredging management of hunting management of fishing restoration of vegetation succession	S'Albufera de Mallorca, Spain Aiguamolls de l'Empordà, Spain S'Albufera de Mallorca, Spain Camargue, France Étang de l'Or, France Salt Marshes in Tejo Estuary, Portugal



irrigation schemes. Instead of an inflow of 330 Hm<sup>3</sup> per annum of freshwater, the lake will receive water inputs equivalent to its open water evaporation when all the dams are completed. There will be major inflows of sea water producing a saline lake of rather stable level (Hollis 1992a). With three dams completed, salinities have soared from their pre-dam winter norm of less than 10 g/l, to values in excess of 60 g/l with catastrophic consequences for the *Phragmites*, *Scirpus*, *Potamogeton*, other fresh or brackish water plants and the wintering and breeding birds that used to depend upon them.

There is direct abstraction of irrigation water from Lac Oubeïra in the El Kala National Park in Algeria. Lac Oubeïra's 46 Hm<sup>3</sup> of water used to be drawn at a rate of up to 80 m<sup>3</sup> per hour (c. 0.7 Hm<sup>3</sup> per year) to supply El Kala, but even this used to leave the town without piped water at times. Between May and September an abstraction of 100 l/sec (c. 1.3 Hm<sup>3</sup> per year) is licensed for withdrawal for irrigation (Stevenson *et al.* 1989). During the drought months of summer 1990, a series of small motor pumps was installed in the edge of Lac Oubeïra for the irrigation of the surrounding fields and many small wells were established in the surface aquifer feeding the lake. As a result, the lake dried out entirely for the first time in its history.

Las Tablas de Daimiel National Park on the Guadiana River in central Spain is an extensive area of reed bed with pools and a peaty substrate. It was sustained by a steady input of calcium-rich groundwater from the La Mancha aquifer and regular winter floods from several rivers which rise on more impermeable rocks. Heavy pumping from the aquifer to irrigate a rapidly developed arable farming system lowered the water level in the aquifer to such an extent that all of the springs dried up. The rivers lost most of their winter flow and all of their summer flow into the aquifer (Llamas 1988). The construction of the Azuer dam on one of the tributaries contributed further to this desiccation. The Daimiel restoration scheme consists of releasing around 30 Hm<sup>3</sup> of water from the Tajo-Segura inter-regional water transfer into the headwaters of the Cigüela river. In order to assist this water to reach Daimiel, a drastic channelization scheme was undertaken on the Cigüela which removed its extensive reed beds, desiccated a number of wetlands and damaged water control structures on other upstream lagoons. In addition, a series of wells were installed around the National Park to feed groundwater to the Park during any critical summer months. Whilst the

restoration scheme has returned flooded conditions to the Park, it is now an area of constant groundwater recharge and the Tajo water is of such different quality to the original groundwater that there are subtle ecological changes under way in the reed beds and peat.

### Changes in the wetland

There can be hydrological changes within the wetland that affect its ecological character directly. The importation of water, infiltration of irrigation water, embankments and drainage schemes can alter the ecology of a wetland quickly.

The extensive cultivation of rice in the Camargue creates a freshwater habitat during the summer months when such areas are naturally limited in extent. One of the effects of the rice cultivation is that there is a strong infiltration into the surface aquifer beneath the fields. This raises the regional water table and tends to cause brackish water to rise in areas around the rice fields (Boulot 1991; DDA 1970).

The protection of Lake Karla in eastern Greece from overflows from the Pinios River and the associated drainage of the lake by means of a tunnel to the sea and deep drainage ditches have had some adverse environmental effects (Gerakis 1992). Whilst some of the one time fishermen have profited from becoming farmers, all of the previous wetland functions have been lost. There is a shortage of summer irrigation water, winter flooding, marine intrusion because of the depleted water table, social stress from the unplanned land allocation, pollution from local agricultural processing plants, severe pollution from agro-chemicals, no local freshwater fish and no waterfowl.

Sebkhet Kelbia in central Tunisia is a periodically flooded lake which occasionally dries without leaving a salt crust. When wet, it holds internationally important concentrations of waterfowl. The lake basin is normally an area of internal drainage with only rare overflows to the sea. The half dozen spills this century have been significant in that there has been significant flood damage downstream, especially in 1969. The capacity of the lake has been reduced from 343 Hm<sup>3</sup> in 1934 to only 169 Hm<sup>3</sup> today because of heavy sedimentation from the inflowing rivers and some erosion of the overflow sill. It has been shown that



this reduction in capacity has had a greater impact on the ecology of the lake than will the future changes resulting from the three large dams now restraining the influent rivers (Hollis & Kallel 1986).

### 2.3.3 Changes in water quality

Nutrient enrichment is one of the most general forms of wetland pollution in many Mediterranean wetlands (Golterman 1992). Many wetlands receive excessive quantities of nitrogen and phosphorus from urban sewage and agricultural runoff. Phosphate-free detergents are starting to be available, belatedly, but agricultural use of fertilisers has increased. Further, many small wetlands are polluted through their use as drains or disposal areas for nearby rural towns (e.g. Lieutaud *et al.* (1992) on Languedoc lagoons in France).

Many Mediterranean coastal waterbodies are now severely eutrophicated. For instance, the tidal lagoons of the Po Delta receive tonnes of nitrogen and phosphorus (Viaroli 1992), the lagoons in the Nestos and Louros and Arachthos

deltas in Greece are reportedly eutrophic (Papayannis 1992b) and Lake Manzalla in Egypt receives untreated sewage and industrial waste (Ramsar Bureau 1993a). As many of these waterbodies are shallow and irregularly flushed, large beds of macro-algae develop. Foul smelling and potentially toxic phytoplankton blooms along with anoxic crises have become more common in lagoons and coastal waters.

Much industrial pollution in the Mediterranean originates from the petrochemical industries that have contributed to the prosperity of the region. Transport and refining of oil is a well recognised pollution threat to coastal wetlands and their wildlife. Extensive oil slicks can devastate coastal wetlands. The manufacture of plastics, pesticides, fertilisers and pharmaceuticals occurs in huge industrial complexes such as those alongside Venice lagoon and the Étang de Berre in the south of France. Agricultural chemicals also find their way into wetlands. Disposal of wastes is a complex problem and there is always the risk of spillages and pollution downstream.

Mineral extraction has scarred and disfigured the Mediterranean for millennia. Modern open cast

Plate 2.3 The petrochemical industry is an important source of pollution in Mediterranean wetlands. Industrial area around the Étang de Berre, France. (Pere Tomàs Vives)





mines such as those that ring Spain's infamous Portman Bay have decimated the fauna of the nearby seabed. The disposal of sewage from expanding tourist and urban conglomerates is a well recognised blight on many wetlands. Alternative and cheap waste disposal systems are urgently required for many forms of industrial, agricultural and urban waste. Wetland filters can assist in ameliorating wastewaters, as suggested for the lagoons of the Po Delta, but are not the universal answer. In many instances the natural ability of wetlands to assimilate wastes can be exceeded and eutrophication and pollution exacerbated.

#### **2.3.4 Unsustainable exploitation of wetland products**

In the Mediterranean, many wetlands are considered to be a community resource. As such, some users try to take the maximum from the wetlands without regard to the appropriate sustainable harvest for all users. Therefore marshes may be over-grazed, lakes and lagoons over-fished and waterfowl hunted without full regard for regulations.

Tamisier (1992) examined qualitative changes in the remaining natural habitats of the Camargue as a result of human pressures. He cited the case of cattle pastures having halved in area whilst the herds had doubled in size due to intensification, including additional artificial feeding. The tourist exploitation of the "authentic" Camargue way of life may be good business, but it is one of the reasons for division of the natural habitat into smaller areas which are in turn damaged by over-grazing and trampling. The annual bag of 150,000 wintering ducks from the Camargue has not changed over the years whereas the amount of hunting has increased markedly. This was seen by Tamisier (1992) as evidence of a decline in "catch-per-unit-effort" and therefore a sign of over-hunting.

#### **2.3.5 Introduction of alien species**

Alien species of plants and animals find their way into wetland habitats by human design and by accident. In the former it is usually believed that the new species will exploit a particular niche in the ecosystem and provide substantially enhanced value to the system. When accidental introductions

Plate 2.4 *Eucalyptus* plantation on the coastal dunes of Merja Zerga, Morocco. (Francesca Crespi Ramis)





occur the whole system can be distorted, but this can equally be the case with planned introductions. In either case there are elements of ecological change under way because of the introduction of the new species to the wetland.

In the Prespa National Park in the 1980s, goldfish *Carassius auratus* was introduced, presumably in the belief that it would offset the falling fish catches. The goldfish population grew quickly in size and numbers and was soon the largest component of the catch. However, it is of relatively low value in the market and subsequent studies have proved that the poor fish catches were the result of over-fishing (Catsadorakis & Crivelli in press).

In the post-war years, ruddy duck *Oxyura jamaicensis* was imported from North America to the Wildfowl and Wetlands Trust Reserve at Slimbridge in England. A number of birds escaped and established a thriving population in Britain. They spread across Europe to Spain where the birds began to inter-breed with the rare and threatened white-headed duck *Oxyura leucocephala* to produce hybrids. An extermination campaign has been launched to save the white-headed duck from extinction in the Mediterranean.

Perhaps the most ubiquitous introduction to the Mediterranean flora is the *Eucalyptus* tree which came from Australia. The tree has a particularly high water demand and has been used in some cases to desiccate wetlands. Elsewhere it has been planted for its fibre, and its ability to grow in very poor soils has allowed the development of a paper-pulp industry. However, it provides little or nothing to the native fauna and it produces no understorey and an impoverished soil profile. Large areas of the dunes and dune slacks at El Kala in Algeria have a semi-commercial *Eucalyptus* plantation. A similar forest within the Odiel Marshes Natural Park in Spain is being eradicated because of its alien nature.

### 2.3.6 Management, neglect and restoration

Human activity can bring positive benefits to wetland habitats through effective management, benign neglect and restoration schemes.

Habitat management measures, when implemented effectively with appropriate monitoring and review processes, can bring substantial gains in wetland

**Plate 2.5** Merja Zerga, a wetland of international importance on the Atlantic coast of Morocco, is undergoing changes in the quantity and quality of its water. (Francesca Crespi Ramis)





functions, products and attributes. The complex of over 10,000 ha of lagoons at Caorle, Venezia, Po Delta and Comacchio have been used for centuries for traditional fishing and aquaculture activities. The "vallicoltura" system of aquaculture is an especially important link between wetland conservation and utilisation of the marshes (Rallo 1992). In this case integrated management has been developed over the centuries. Taris (1990) has described the processes and costs involved with the management plan for the private nature reserve of Tour du Valat in the Camargue, France. The intense management activity conserves biodiversity, allows ecological research to be carried out and also permits farming and grazing on the same lands. He showed that the extra costs of nature reserve management, including the ecological monitoring, was 50 ECU per ha in addition to the compulsory fixed costs.

Human activity can be highly beneficial to certain types of Mediterranean birds through the promotion of the salt industry with its evaporating basins. Around 70,000 greater flamingos *Phoenicopterus ruber roseus* occur in seven countries in the western Mediterranean. Breeding occurs every year in colonies of up to 20,000 pairs on an artificial island in the Salines of the Camargue. There is also regular breeding at Fuente de Piedra in Andalusia. Birds converge on the natural breeding sites in Spain and Tunisia only if they have flooded after heavy autumn and winter rains (Johnson 1992). Throughout the flamingo's range in the Mediterranean, industrial salines occur along with a few artisanal operations. This man-made or modified habitat is highly beneficial to the flamingo because water levels are ideal, food is often abundant and predictable, and many are efficiently protected. In Portugal, active and abandoned salines can support relatively large densities of breeding black-winged stilts *Himantopus himantopus*. In the Tejo estuary, fish farms have only one breeding pair per 10 ha whilst active salines have double this density and inactive salines have 3 breeding pairs per 10 ha. The breeding productivity of salines for black-winged stilts can be substantially increased by active management (Rufino & Neves 1992).

Merja Zerga, on the north Atlantic coast of Morocco, is a shallow tidal marine lagoon of substantial international importance; its large and productive mudflats (3625 ha) provide the most important site for overwintering and passage waterfowl in Morocco (Michel and Salathé 1991). The Ramsar Bureau (1990) notes that

"Merja Zerga is ... the premier wetland site in Morocco, and it is the most important wintering area in Morocco for several tens of thousands of waterfowl". A recent hydrological survey combined with existing literature revealed, for the first time, that whilst freshwater was a small portion of the total water flows into and out of the wetlands, local groundwater sources fed key local freshwater habitats (Goldsmith *et al.* in press). The lagoon has maintained its ecological importance for waterfowl, fisheries and grazing despite its apparent neglect by the water managers for the region both in terms of active management and monitoring. Major hydrological changes in water quantity and quality have been caused by the desiccation of one river system for irrigation and the six-fold increase in fresh, but polluted, inputs through the redirection of the drainage from a southern catchment and irrigation perimeters into Merja Zerga via an artificial canal (Conservation Course 1994).

Wetland restoration schemes are becoming more numerous in the Mediterranean (Montes *et al.* 1995). At Doñana, in Spain, the flooding of the Marismas has been halted by an agricultural drainage scheme outside the Park. Flooding has been restored through the pumping of river water onto the marsh and the removal of a river wall to allow estuarine water onto the marsh (Hollis & Jepsen 1991). Whilst this scheme seemed to have been effective initially, more and more questions are being raised about its long-term value as monitoring of its effectiveness has been continued. Hunters are potentially a powerful lobby for wetland conservation, and also provide some economic benefits to land owners. The relative wealth of hunting associations also allows research staff to be appointed and can finance wetland restoration projects such as that at Bozza Marsh on Lake Maggiore (Sorrenti & Concialini 1992). Finally, at Lac Fetzara in Algeria, action by the local hydraulic engineers to avert flooding of the steelworks at Annaba led to the almost inadvertent restoration of the lake and wetland system. Proper management of the outlet sluices now provides water for irrigation, an extended grazing season, flood protection, reinstated waterfowl habitat particularly for greylag geese *Anser anser*, and hunting opportunities (Stevenson *et al.* 1989). This inadvertent wetland restoration has, of course, not been associated with a monitoring programme and so its long-term benefits and effectiveness are not being documented.



## 2.4 Causes of adverse ecological change

Almost all Mediterranean wetlands have been influenced to some extent by centuries of human activity. As the new millennium approaches, almost all Mediterranean wetlands are subject to intense development pressure and are in danger of being degraded or destroyed. To prevent further ecological change, the underlying and often invisible factors, the immediate policy and institutional elements, and the more apparent and almost always highly visible causes of adverse ecological change in wetlands must be addressed (Hollis 1992b).

In terms of monitoring, therefore, it is usually insufficient to assess only the actual changes occurring in the wetlands. The processes in society leading to these normally adverse changes are, by then, already under way to such an extent that they may be unstoppable. A comprehensive wetland monitoring programme therefore has to have elements in the wetlands, but other components in the offices of development agencies and in the debating chambers where public policy is formulated.

### 2.4.1 Underlying factors

The root causes of the continuing loss and degradation of Mediterranean wetlands are: population pressure; lack of public and political awareness of wetland values; lack of political will for wetland conservation; over-centralised planning procedures; and financial policies and irregularities. External factors include: EC policies; activities of Development Assistance Agencies, although they are revising their practices; and historical legacies. The more immediate causes relate to: weak conservation institutions; sectoral organisation of decision making; deficiencies in the application of environmental impact and cost-benefit analysis; the passing of good legislation without subsequent enforcement; a lack of trained personnel; limited international pressure; and alliances which promote studies rather than action (Hollis 1992b).

### 2.4.2 Apparent causes

The apparent causes of wetland loss and degradation include activities that directly affect

the ecological character of the wetland. These are, in fact, manifestations of the underlying causes of wetland loss and are generally inseparable from the pressures of population growth and further economic development. Major, and apparent, causes of wetland loss and degradation in the Mediterranean include:

- agricultural intensification,
- urbanisation and industrialisation,
- tourism,
- expanding fisheries and aquaculture projects,
- hunting activities.

Whilst these causes are listed individually they are not totally independent. For example, water pollution can be caused by industrial and agricultural practices as well as tourism and aquaculture developments. Increased tourism can also lead to the conversion of wetlands to resorts and to over-extraction of water. The intensification of agriculture through irrigation, booming tourist resorts and burgeoning cities, and rising demand for electricity can combine to create dams and water diversion schemes including hydro-electricity generation which have radical effects on downstream wetlands. This interdependence must be borne in mind when drawing up management plans and monitoring programmes to address the causes of wetland loss and degradation. Obviously, when the changes are monitored in the wetlands, it may be far too late to take any action to counteract the forces of degradation.

### Agricultural intensification

Agriculture is one of the main industries throughout the Mediterranean. Everywhere it benefits from some degree of irrigation and there are substantial pressures for both expansion and intensification through improved irrigation, better drainage, increased use of agro-chemicals and fertilisers, and enhanced mechanisation. In the south and east of the Mediterranean, population growth is a forcing factor (Golini *et al.* 1990). In the EU, until recently, the Common Agricultural Policy with its guarantee of high prices has been a major engine of intensification (Baldock 1990). The enlargement of the cultivated area, the elevated demand for irrigation water and the runoff of nutrients and agricultural chemicals can all bring ecological change to wetlands (Viaroli 1992).



**Plate 2.6** Ancient agricultural systems are being abandoned and replaced by intensive agriculture, increasing the use of chemical fertilizers and pesticides. View of the veles, a traditional system for rice cultivation, near s'Albufera de Mallorca. (Gabriel Perelló Coll)

Drainage of wetlands, shallow lakes and lagoons is one of the easiest and most dramatic wetland conversions that humans can wreak in the pursuit of increased agricultural land area (Hollis 1990). The construction of dykes, sluices, pumping stations and under-drainage systems are usually the mechanisms employed. Where peat lands are drained for agriculture, the oxidation of the newly aerated peat leads to rapid shrinkage and reductions in ground level. In the lower reaches of the Strymon river in northern Greece a shallow lake was drained to yield highly productive peat soils. These have gradually decayed and most farmers suffer drainage problems (Psilovikos 1992).

Irrigation schemes can affect wetlands through: the damming of rivers; the reduction of river flow by inter-basin transfer or the enhanced evaporative losses from the fields themselves; by the salinisation of groundwater and downstream flow as evaporation concentrates salts in the water draining from the fields; by conversion and drainage of the wetlands or at least their edges; and through the adverse effects of fertiliser and agricultural chemicals being washed from the intensively cultivated fields (Llamas 1988; Hollis 1990; DHKD 1992; Munteanu & Toniuc 1992).

### Urbanisation and industrialisation

The growth in Mediterranean population, their increasing concentration into urban areas, and the importance of industry in Mediterranean cities puts particular pressure upon wetlands (Golini *et al.* 1990). In some cases, notably coastal areas such as near Montpellier, France (Tamisier 1992) and Annaba, Algeria (Stevenson *et al.* 1989), there is incursion into the wetlands especially for holiday homes and hotels. All cities draw large amounts of water from their hinterland, Athens being notable for recently tapping the River Evinos which feeds the Messolonghi wetlands on the other side of Greece (Hollis 1993). Industry produces wastes and all cities must dispose of their sewage (World Bank and EIB 1990).

The post World War II management of the Rhône illustrates the widespread and interrelated impacts of a complex scheme to provide cities with electricity, navigation and irrigated crops. The construction of 48 hydro-power dams on the Rhône, 19 sluices to control 200 km of river bypass canals, and the diversion of water out of the catchment for hydro-power generation in the headwaters and for irrigation on the Mediterranean



coastal plain have had a profound effect on the river. In the upper basin, the spring and summer peak flows have been reduced whilst winter flows have risen as a result of the hydro-power dams' operation. At Porte du Scex, where the Rhône flows into Lake Geneva through the Granges Ramsar site, the ratio of the maximum to the minimum discharge has fallen from 8.8 before 1930 to only 3.8 after 1951. Where the river divides around the Camargue delta, the discharge has fallen by 10% because of diversions from the river so allowing upstream migration of saline sea water. The hydro-power schemes have reduced flow from April to December but increased it substantially in the winter months of peak electricity demand. In addition to the ecological effects, this reduction in low flows has been adverse for cooling water to the nuclear power installations along the Rhône. The reduction in the sediment load of the Rhône from around 50 million tons per year in the 1930s to less than 3 million tons today, because of the trapping of silt by the dams, has starved the Rhône delta of material. The result has been erosion of the face of the delta at a rate of between 3 and 10 metres per year for the last decade (Corre 1992).

### Tourism

In the Mediterranean, tourism has been a serious factor in the degradation and loss of wetlands. Examples of some of the worst effects of tourism include: the filling of wetlands in Languedoc, France, to provide land for low value mass tourism; the pumping of freshwater from the coastal dunes of Doñana, Spain, for Matalascañas (Hollis, Mercer & Heurteaux 1989); the illegal construction of summer houses on the Louros sand bar at Messolonghi, Greece (Handrinos 1992); and the discharge of untreated wastes into the Faro, Obidos and Albufeira lagoons in Portugal.

Well managed tourism can be compatible with the conservation of wetlands. However, this may attract criticism, such as in the Camargue, France (Tamisier 1992) where many land owners maintain freshwater marshes to attract visiting hunters. In Mallorca, a major habitat restoration and diversification is under way to enhance both the ecological and economic importance of s'Albufera. In certain areas there is a need to restrict tourism at certain times of the year (e.g. where rare plants occur or when colonial birds nest on the beaches). The potential economic benefits of wetland-related tourism for local people and their economic

well-being could be profound, especially if tourists, such as birdwatchers are attracted outside the main seasons.

In planning the development of further wetland-related tourism, local authorities with the advice of scientific and conservation bodies need to consider all the ramifications (Ramsar Bureau 1993b). For example, in planning drinking water availability for tourist developments steps may need to be considered to guarantee the conservation of nearby wetlands and those further downstream. Furthermore, the local waste treatment systems may need to handle greatly increased loadings during the summer tourist season. Other problems arise when the wildlife is disturbed and the soil around wetlands is compacted and runoff increases. These factors can be incorporated into development plans to ensure that the wetland is enhanced and not degraded. Obviously, there needs to be a monitoring programme that can make available to developers information about wetlands likely to be affected by their projects and a monitoring programme for the development plans themselves.

### Fisheries and aquaculture

Fishing was formerly the main activity in freshwater lakes, large rivers and lagoons within the Mediterranean region. However nowadays, habitat degradation, agricultural development and other development activities have largely supplanted the traditional and sustainable fishing practices (Crivelli 1992). In some instances, fishing has either disappeared (e.g. in many large rivers and some lakes) or has tended to become a marginal activity (e.g. lagoon fishery in the Étang de l'Or, France). The main factors involved in the decline of fisheries within the Mediterranean are habitat degradation, pollution and eutrophication, introduction of alien fish species and over-fishing, often with new technology (Crivelli 1992).

All these factors have contributed to the decline or the disappearance of native fish species as well as to the depletion of stock of commercial fish species such as the valued common carp *Cyprinus carpio* in Lake Koronia, Greece, and the grey mullets *Liza aurata* and *Chelon labrosus* in the Albufera des Grau, Balearic Islands (Cardona & Pretus 1992). Where traditional lagoon fishing is still practised with techniques that have virtually remained unchanged, it is considered to be compatible with the



maintenance of biodiversity and the integrity of Mediterranean wetlands. However, over the past few decades intensive aquaculture has developed with an emphasis on high value species such as sea bass *Dicentrarchus labrax* and gilthead sea bream *Sparus aurata*.

In freshwater wetlands, trout farms are very numerous and in lakes and reservoirs cage-structures for rearing other species have become more common, especially in Italy. Such practices generally increase the risk of eutrophication and the release of pesticides and growth hormones to the natural environment. Additionally, freshwater wetlands are being stocked with alien species, such as the grass carp *Ctenopharyngodon idella*. At Lac Oubeïra in Algeria this resulted in the loss of all the rich emergent and submerged vegetation. Furthermore, the aquaculture industry is still beset by an over-reliance on supplies of fry from natural environments (e.g. from Lac Ichkeul in Tunisia and Lac Tonga in Algeria for Italian fish farms), the introduction of alien species and the degradation of natural wetlands as on the northern shores of the Amvrakikos Gulf in Greece. In coastal wetlands, aquaculture has contributed to habitat damage or loss, namely enclosures in lagoon systems, substrate

management and disturbance in clam exploitations and transformation of salines (e.g. Sado Estuary, Portugal).

### Hunting activities

Waterfowl hunting may not be a cause of wetland loss, but at many Mediterranean wetlands the intensity of hunting is so great that it can degrade them through disturbance, lead poisoning and direct effects on waterfowl populations (Tamisier 1987). Management activities in the wetlands to favour hunting, such as reed cutting and the unseasonal flooding of marshes as in the Camargue, can degrade the quality and diversity of wetland vegetation. Information on the extent of wetland degradation as a result of hunting is often inadequate for effective management purposes: hunting statistics often under-report the number of birds killed; data on birds that die of lead poisoning are incomplete, and information on the degree of disturbance variable (Perco & Perco 1992).

The individual wetland manager can contribute towards sustainable hunting through effective enforcement of regulations and open seasons, the

**Plate 2.7** Tourist development and management for hunting are some of the factors that affect the quality and diversity of Mediterranean wetlands. View of a tourist resort and excavated area for hunting (in the foreground), Albufera de Pollença, Mallorca. (Pere Tomàs Vives)





prevention of poaching and the maintenance of a semi-natural and diverse series of wetland ecosystems (Sorrenti & Concialini 1992). Conservative risk-averse strategies for waterfowl hunting have been proposed for implementation at the national or supra-national level. Such strategies include improved licensing; linking the number of hunters to the potential carrying capacity; creating a network of disturbance-free zones; closure of the hunting season before the spring migration begins; introducing non-toxic shot; restricting the hunting of declining species; banning hunting of threatened species and those that closely resemble them; collecting data on hunting intensity; stricter management of tourist hunting; and more effective policing of regulations to reduce poaching. These measures and strict enforcement of hunting regulations are needed throughout the migratory waterfowl flyways.

Monitoring of bird numbers at a wetland site can help to identify both the impact of hunting and carrying capacity, whilst internationally coordinated bird counts are essential if long-term trends in overall waterbird populations are to be determined.

## 2.5 Conclusion: Ecological change and monitoring

In conclusion, ecological change in the form of relatively rapid human-induced degradation of Mediterranean wetlands is widespread and active. The functions and values of Mediterranean wetlands are being diminished by this ecological change. There are far fewer examples of a positive impact of human interference on wetland ecosystem functioning through management or restoration.

The main categories of processes producing adverse ecological change are: change in of wetland area; changes in the water regime; changes in water quality; unsustainable exploitation of wetland products; and the introduction of alien species. The driving forces for these ecological changes are social, economic and political but the actual agents are such human endeavours as agricultural expansion and intensification, urbanisation and industrialisation, tourism, fisheries and hunting.

The management of Mediterranean wetlands demands that the extent of ecological change be monitored so that corrective action can be taken.

This is feasible when it concerns, for example, duck numbers and the impact of hunting because the management agency can expect to exert a degree of control within the wetland area itself. However, changes in the water regime of the wetland brought by dam construction to satisfy urban and irrigation demands in another river basin cannot be so easily managed. Indeed, by the time that a field monitoring programme has identified the ecological changes, it is probably far too late to take any management action since the dam and water transfers will be operational. The management of schemes that have potential adverse effects on the ecological character of wetlands requires an institutional structure for the integrated management of all of the water demands within entire river basins. The monitoring of the ecological impacts of climate change and global sea level rise on Mediterranean wetlands (Jeftic *et al.* 1992) will be important because coastal wetlands are likely to be good indicators of global ecological change. However, it will be hard to disentangle the effects of local human activity from the more general effects of global environmental change. The management of global environmental change clearly has to take place at international level, but local ecological monitoring may reveal opportunities for site specific mitigation and management.

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# 3 Framework for designing a monitoring programme

C. Max Finlayson



## ABSTRACT

*A framework for assisting with the design of ideal and effective monitoring programmes is presented. The framework is placed within the context of a management system that provides the means of responding to the results of the monitoring programme. It is immediately noted that monitoring is not the same as surveillance which is generally undertaken without a particular reason for collecting the data or information. The framework is not a prescriptive recipe for any particular monitoring programme. It is a series of steps in a logical sequence. The general headings for these steps are listed below:*

- *Identify the issue or problem*
- *Set the objective*
- *Establish the hypothesis*
- *Choose the methods and variables*
- *Assess the feasibility and cost effectiveness*
- *Conduct a pilot study*
- *Collect the samples*
- *Analyse the samples*
- *Report the results*
- *Implement management and evaluate the project*

*These steps are presented pictorially and described in the text. Feedback loops within the framework provide the means of reassessing the effectiveness of the preferred method in achieving the objective (i.e. provide the means for evaluating the project). Three hypothetical examples that illustrate the use of the framework (but do not define the detail) for designing a monitoring programme are given.*



### 3.1 Introduction

Environmental monitoring has received more and more attention in recent years. At a global level this has arisen as awareness of the extent of environmental degradation and habitat loss has increased. Wetlands, including those of the Mediterranean, have not been exempt from this general and widescale degradation (see, for example, cases described in Finlayson *et al.* 1992). Such is the concern at the extent of global wetland degradation that more and more effort is being directed towards developing effective management processes and responses to problems. In many instances this effort is being held back by a lack of relevant information on the nature of the problem, the cause of the problem and the effectiveness of management procedures and actions. Effective monitoring programmes can help overcome such problems.

In a general sense monitoring addresses the general issue of change or lack of change through time and at particular places. Monitoring is built upon survey and surveillance but is more precise and oriented to specific targets or goals (Goldsmith 1991).

*Survey is an exercise in which a set of qualitative observations are made but without any preconception of what the findings ought to be.*

*Surveillance is a time series of surveys to ascertain the extent of variability and/or range of values for particular parameters.*

*Monitoring is based on surveillance and is the systematic collection of data or information over time in order to ascertain the extent of compliance with a predetermined standard or position.*

Thus, monitoring is built on a time series of surveys and differs from surveillance by assuming that there is a specific reason for collecting the data or information (see Spellerberg 1991, Goldsmith 1991, Furness *et al.* 1994).

The effectiveness of monitoring varies considerably. An effective monitoring programme is not necessarily complex nor expensive. Effectiveness is gauged by the relevance and timeliness of the data or information collected. Simple approaches to monitoring can be very effective if they are well designed.

A framework for assisting with the design of a monitoring programme is presented. The framework applies to all forms of monitoring (e.g. changes in the area of a wetland, the ecological health of a wetland, or the underlying reasons behind the loss of wetlands). The framework is not prescriptive. It is not a recipe for a particular type of problem or a particular type of wetland – this would be presumptuous given the many differences between sites, the problems and the resources available. It presents a series of steps that will assist those charged with designing a monitoring programme to make decisions suitable for their own situation. A person using the framework will make these decisions based on some degree of knowledge and/or expertise. The framework is not a substitute for knowledge or expertise.

Where monitoring programmes already exist, the framework can be used to ensure that the monitoring is being done in a logical and well structured manner. All monitoring programmes should be regularly reassessed and, where necessary, modified or even terminated. The framework can thus be used as a tool to assist with the revision and evaluation of existing programmes.

The Ramsar Convention has, in parallel, also considered change in ecological character and monitoring of internationally important sites. At the Sixth Conference of the Contracting Parties of the Convention in March 1996, a framework for monitoring and guidelines for interpreting change in ecological character were adopted. As with this MedWet guide, the framework was based on that in Finlayson (1994).

### 3.2 Management and monitoring

Even a well designed monitoring programme could have little value if the information that is collected is not utilised or does not influence the management process for that locality or site. Ideally, the locality or site will be subject to an interactive and holistic management plan that provides the means of responding to the information obtained from the monitoring programme. If a formal or official management plan does not exist or is not being effectively implemented it is critical that mechanisms to make use of the information collected from a monitoring programme are identified and developed. Information collected by



non-governmental groups or research institutions is often used to arouse public pressure to improve specific management processes, to implement existing legislation and regulations or to introduce new legislation or management practices.

Constable (1991) outlines the vital connection between a formal management procedure and an environmental monitoring programme. Essentially, monitoring provides the means of measuring the output of the management procedure – that is, it provides the means of measuring the (observed) state of the environment and the extent to which it may have been altered. If the management objectives are not being met, the existing legislation or regulations that affect the site (or location) are used to adjust the management activities. Importantly, a monitoring programme can be established either before or after a particular management activity is implemented. If monitoring is conducted before a particular management decision is taken it is essential that the information collected is then used to influence the management activities.

Effective management is partly dependent on the provision of adequate information. This can come either from official or unofficial monitoring programmes. The origin of the information is not the critical issue. If the information is valid and provides a measure of change or likely change it can be used to promote appropriate management actions.

### 3.3 A framework for monitoring

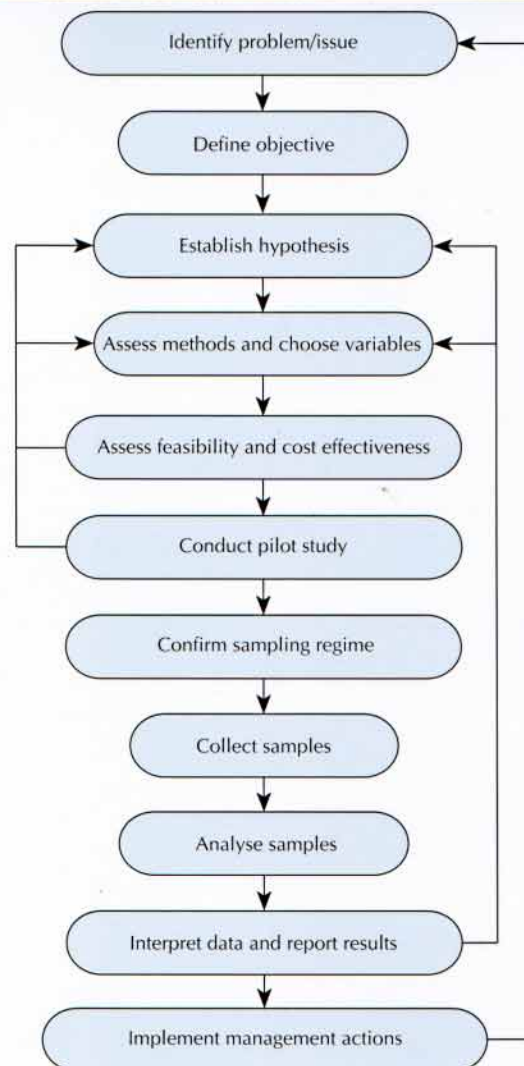
The existence of a monitoring programme does not guarantee that it is an effective management tool. For example, monitoring programmes that are data rich and information poor are not effective management tools. Effectiveness is further reduced if the programme provides misleading information. Frameworks for designing monitoring programmes are tools to assist managers and planners. It is important to reiterate that the framework does not provide the answers – those responsible for the design provide the answers.

Ideally the development of a monitoring programme should be a straightforward and cooperative process between managers (who make decisions) and scientists (who provide expert advice and interpret data). Simplistically, 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. But, how often do monitoring programmes fail to meet the management objectives or, even worse, provide misleading information? Adherence to a logical framework for designing monitoring programmes cannot eliminate such situations, but it can provide the means to identify the limits of a programme and thereby potentially reduce the incidence of such cases.

The framework is presented pictorially in Figure 3.1. Key aspects of the various components of the framework are described below, based on material

**FIGURE 3.1** A framework for designing a wetland monitoring programme.





presented in a number of published sources (Green 1984, Maher & Norris 1990, Goldsmith 1991, Spellerberg 1991, Finlayson 1994, Maher *et al.* 1994). A summary of the points to consider when using the framework is given in Table 3.1. Three hypothetical and practical examples of using the framework are given in Tables 3.2, 3.3 and 3.4.

The framework illustrates an ideal and perhaps even a hypothetical situation. The amount of time spent considering each step in the framework will depend on time and resources available. As the framework is not prescriptive there is no expectation that every step should be given equal attention. Managers and designers

will make their own decisions based on local circumstances – the framework provides a guide to assist them in making these decisions.

### 3.3.1 Identify the issue or problem

Identification of the issue that leads to a change in the ecological character of a wetland is a crucial first step. This needs to be done clearly and unambiguously. It is also linked with setting the objective. Once this has been done it is possible to formulate management activities, including further investigations, to shed light on the issue/problem and to provide the justification for monitoring.

**TABLE 3.1 Summary of key points to consider when using a framework for designing a wetland monitoring programme.**

Identify the issue or problem	State clearly and unambiguously State the known extent and most likely cause Identify the baseline or reference situation
Set the objective	Provides the basis for collecting the information Must be attainable and achievable within a reasonable time period
Establish a hypothesis	Supports the objective and can be tested
Choose the methods & variables	Specific for the problem and provides the information to test the hypothesis Able to detect the presence, and assess the significance, of any change Identifies or clarifies the cause of the change
Assess the feasibility & cost effectiveness	Determine whether or not it can be done regularly and continually Assess factors that influence the sampling programme: availability of trained staff; access to sampling sites; availability and reliability of specialist equipment; means of analysing and interpreting the data; usefulness of the data and information; means of reporting in a timely manner Determine if the costs of data acquisition and analysis are within the budget If necessary, reassess the hypothesis, and the methods and variables
Conduct a pilot study	Time to test and fine-tune the method and specialist equipment Assess the training needs for staff involved Confirm the means of analysing and interpreting the data If necessary, reassess the hypothesis, and the methods and variables
Collect the samples	Staff should be trained in all sampling methods All samples should be documented: date and location; names of staff; sampling methods; equipment used; means of storage or transport; all changes to the methods Samples should be processed within a timely period and all data documented: date and location; names of staff; processing methods; equipment used; and all changes to the protocols
Analyse the samples	Sample and data analysis should be done by rigorous and tested methods The analyses should be documented: date and location; names of analytical staff; methods used; equipment used; data storage methods
Interpret the data and report the results	Interpret and report all results in a timely and cost effective manner The report should be succinct and concise, indicate whether or not the hypothesis has been supported and contain recommendations for management action, including further monitoring If necessary, reassess the hypothesis, and the methods and variables
Implement management & evaluate the project	Review the effectiveness of all procedures and where necessary adjust or even terminate the programme



**TABLE 3.2 A hypothetical example of a programme to monitor potential problems caused by a tourist facility developed alongside a freshwater lagoon. In this example it is assumed that adequate baseline data on water depth exists prior to monitoring commencing. In the space available it is not possible to explain the rationale behind the choice of objectives, methods, etc. but it is reiterated that the designers need to make decisions and record the reasons and detail on which these are based.**

General problem/issue	A large tourist complex including an 18 hole golf course has been developed alongside a freshwater lagoon important for waterbirds.
Specific problem/issue	Water levels in the lagoon will be lowered as water is extracted for use in the hotel and on the golf course.
Objective	Monitor the rate of water extraction and the level of water in the lagoon.
Hypothesis	The rate of water extraction should not exceed (identify rate) on any occasion. The water level in the lake should not vary significantly (within 95% confidence limits) from the long-term average ( $x \pm y$ metres) during the summer months of July and August.
Methods & variables	A gauge (identify specifications of model) is fitted to the only pump being used to extract water from the lake. Data from the gauge are collected (identify how and at what time interval). Water depths are monitored (identify how) and the data collected (identify how and at what time interval). The data are assessed daily and stored in a database (define database and location). Statistical analyses are done (identify test method).
Feasibility/Cost effectiveness	Identify necessary equipment (e.g. automatic recording or manually read gauge; automatically recording depth gauge or manually read gauge board) and establish a checking and maintenance schedule. Train staff in checking and maintaining the equipment. Establish database and familiarise staff with statistical methods. Cost staff time and equipment and confirm budget.
Pilot study	Test equipment under field conditions and check reliability of recordings. Confirm all documentation procedures and statistical methods. Train staff in equipment maintenance and statistical analysis.
Sampling	Samples are not being collected but check field recording equipment is adequate and data are being recorded.
Sample analysis	Not applicable.
Reporting	Data statistically analysed and reported (identify to whom and within what time period) with conclusions and recommendations for management action and/or further monitoring.
Implement management & evaluate the project	Stop monitoring if/when water extraction is shown to be non-damaging.

Where possible, the extent or scale of the problem (or likely problem) should also be identified (e.g. will the entire wetland or a number of different wetlands be affected?). Knowing the likely extent of the problem could be made difficult unless the ecological character of the wetland has been adequately described (e.g. how large is the wetland and how much water does it contain?). Thus, baseline or reference data are needed. To establish the baseline it may be necessary to review existing information such as published research, management, monitoring and policy documents and local knowledge.

The cause (or most likely cause) of the problem should also be identified (e.g. pollutants added to an inflowing stream, or over-exploitation of a particular fish species). If the cause is not known an investigative programme should be implemented, but it can be difficult to establish cause-and-effect relationships between an activity and observed features of the environment. Often such

information is not available and given the urgency of many situations little effort is made to obtain it. However, without such information it can be difficult to decide what should be monitored.

### 3.3.2 Set the objective

The objective provides the basis for collecting the information. Imprecise or inadequate objectives negate the usefulness of a monitoring programme. Simply stating that an excessive level of water extraction should not occur is insufficient. The objective must be precisely stated and specific. A surveillance programme can occur without a specific objective, but a monitoring programme cannot; the objective is the starting point of a monitoring programme. When more than one objective is identified they should be prioritised in order to make the best use of time and resources. In such instances each objective should still be addressed.



Explicit statements not only assist in defining the sampling programmes, but in long-term programmes also enable new staff to continue the work in a consistent manner. The objectives provide the basis for obtaining the required information over a specified time period. They need to be realistic and achievable within a reasonable timeframe using measurable parameters.

### 3.3.3 Establish the hypothesis

The objective is supported by an explicit hypothesis. A hypothesis that asserts to simply “assess significant change” is not explicit and should be altered to indicate the required level of change (i.e. it exceeds a preset level or standard, or differs from the long-term mean value by more than a specified level of statistical significance). In other words, a hypothesis that can be tested on the basis of the collected data

or information is required. If this is not done it is not possible to know whether the objective has been attained or not. When determining whether or not a hypothesis has been supported by the data/information, the sources and extent of variability in the data/information must also be recorded. This is particularly important when the natural fluctuations (e.g. in water depth or population levels) are highly variable or even unknown. The hypothesis should be based on sound information.

Hypotheses are often not formulated. Hypothesis-free monitoring has rarely been successful or cost effective. Surveillance is generally done without formulating a hypothesis and can be useful, but may not provide evidence of the linkage between cause and effect that is necessary for management purposes. The significance of the results must be assessed if the programme is to be useful for management actions.

**TABLE 3.3** A hypothetical example of a programme to monitor potential loss of wetland habitat by drainage within a river delta. In this example it is assumed that adequate baseline data on the extent of wetland in the delta exist prior to monitoring commencing. In the space available it is not possible to explain the rationale behind the choice of objectives, methods, etc. but it is reiterated that the designers need to make decisions and record the reasons and detail on which these are based.

General problem/issue	Irrigated agriculture is being expanded within the river delta.
Specific problem/issue	Remaining wetlands within the delta are being drained to be used for agriculture.
Objective	Monitor the extent of wetland area within the delta.
Hypothesis	The area of wetland within the delta should not be decreased significantly (95% confidence limit) from the current area (define area and identify the confidence levels around this value).
Methods & variables	Aerial photographs are flown (details of flights, heights, type of photography, etc.) on one occasion each year (identify preferred date and alternatives in case of unforeseen difficulties with equipment or weather) over the entire delta (establish boundaries) and compared to the baseline value. Identify means of mapping the wetland area from the photographs and storing these data or otherwise assessing whether or not any wetland has been lost. Assess accuracy of the data. Identify ground inspection processes in case photography is not available for any reason or period of time.
Feasibility/cost effectiveness	Establish the availability of the equipment, the suitability of the photographs, ground inspection techniques and mapping techniques, etc. Determine costs of obtaining and interpreting the photographs and assessing the data and ground surveys. Identify statistical limits on the data.
Pilot study	Test equipment under field conditions and check reliability of data interpretation methods, statistical procedures, etc. Ground truthing may be necessary to confirm reliability of data. Train staff in collecting and interpreting the data and statistical analysis.
Sampling	Collect aerial photographs, interpret and store data. Undertake ground surveys.
Sample analysis	Statistically compare results to baseline.
Reporting	Statistical analysis interpreted and reported (identify to whom and within what time period) with conclusions and recommendations for management action and/or further monitoring.
Implement management & evaluate the project	Stop monitoring if/when it is shown that drainage is not occurring.



**TABLE 3.4 A hypothetical example of a programme to monitor the potential effect of development policies of government agencies on wetland habitats. In this example it is assumed that access to the necessary information is unrestricted and the location and values of the important wetland have been identified. In the space available it is not possible to explain the rationale behind the choice of objectives, methods, etc. but it is reiterated that the designers need to make decisions and record the reasons and detail on which these are based.**

General problem/issue	Increased industrial development is planned (identify region concerned).
Specific problem/issue	The industrial development will result in infilling and drainage of the last remaining wetland within the region.
Objective	Monitor the proposed development plans put forward (identify the agency).
Hypothesis	The agency should not infill and/or drain the wetland (identify the site).
Methods & variables	Select appropriate documents and develop means of obtaining them in a timely manner. Establish a process to scrutinise the documents to determine if any such proposals are being developed, even if only at the feasibility stage. Develop means to store the documents. If documents are not readily available prepare manual inspection of sites or publicity announcements, etc.
Feasibility/cost effectiveness	Determine the extent of documentation and filing processes used by the agency and whether or not these can be effectively scrutinised in time. If this is not possible identify key indicator documents or even officials to target. Establish costs of obtaining and storing documents or contacting key officials.
Pilot study	Assess the time and expertise needed to successfully obtain and scrutinise the documents that can be obtained. Train staff to identify key indicator topics, etc. Revise methods or even objectives if documents cannot be obtained.
Sampling	Establish a process to obtain the documents in a reasonable time period and to store them to facilitate the scrutiny process.
Sample analysis	Not applicable.
Reporting	Identify important proposals that may affect the wetland and report (identify to whom and within what time period) with conclusions and recommendations for management action and/or further monitoring.
Implement management & evaluate the project	Reduce the frequency of monitoring if/when it is shown that developments are well-planned.

### 3.3.4 Choose the methods and variables

Many monitoring methods are available. When assessing which methods are appropriate for monitoring a specific problem or site it is necessary to be aware of the advantages and disadvantages of the alternatives in relation to the level of protection that is required. A literature review and expert advice are essential. Above all, the monitoring objective and hypothesis need to be kept in mind; can the method detect change at the required level and over the chosen time period?

In choosing methods and/or variables it is necessary to know what level of change is acceptable (the hypothesis) and whether the preferred method(s) can account for potential sources of variability in the data or information being collected. The following parameters need to be considered when deciding which method to use:

- existence and adequacy of baseline information,
- general approaches for collecting data/information,
- number and location of sampling sites,
- sampling frequency,
- sample replication,
- specific techniques for collecting the samples,
- techniques for processing and/or storing samples,
- protocols and means of storing the data or information,
- methods of statistically analysing the data,
- processes for interpreting the data and information.

In a general sense, the methods need to be able to detect the presence of any change, assess the significance of the change and identify or clarify the cause. Where adequate methods do not exist, well directed research is needed to develop or



identify specific techniques. Methods that do not allow the hypothesis to be assessed should not be used.

### **3.3.5 Assess the feasibility and cost effectiveness**

Once a method has been chosen and a sampling regime identified it is necessary to determine whether or not it is actually feasible to undertake the programme on a regular and continual basis. After this assessment it may be necessary to revise the hypothesis and/or the methods and variables. Thus, factors that influence the sampling process and continuity of the programme need to be considered, for example:

- availability of trained personnel to collect and process the samples,
- access to sampling sites,
- availability and reliability of specialist equipment for sample collection or analysis of samples,
- means of analysing and interpreting the data,
- usefulness of the data and information derived from it,
- means of reporting in a timely manner,
- financial and material support for continuing the programme.

If the monitoring programme is contained within a structured management plan these factors should be easily assessed. If it is not contained within such a plan the assessment may be more difficult; great care should therefore be exercised.

In undertaking the feasibility assessment, the cost effectiveness needs to be considered. The aim of a sampling programme is, with few exceptions, to collect useful data or information with the least cost. The costs of data acquisition and analysis should be determined and considered in terms of the budget and the objective of the programme. This assessment could benefit from independent and expert advice. Ideally, the cost effectiveness assessment would influence the budget allocation for the programme. If an adequate budget is not available, the programme may need to be reduced or even abandoned. Inadequate funding should not be used as a reason to reduce the scientific rigour of a programme. The goal is to obtain valid data for management purposes or to influence management decisions.

### **3.3.6 Conduct a pilot study**

Before launching a large scale programme a pilot study is essential in order to save time and resources in the future. This is the time to fine-tune the method and individual protocols and test the basic assumptions behind the method and sampling regime. Some idea of the rigour of the method and the need to make changes in the design or particular techniques for collecting or analysing the data can be obtained at this stage. This is the time to make changes to the procedures that have been chosen. It can be very expensive and even nullify a programme if changes are made at a later date. Specialist field equipment should be tested in the pilot study and, if necessary, modified based on practical experience. It is also the opportunity to assess the training needs for staff involved.

The means of analysing the data also require testing. If statistical analyses are being used they should be tested with data from the pilot study. For example, possible violations of statistical assumptions such as non-normally distributed data, non-independent data, and insufficient replication should be established and compensatory action taken. It may not be important that all statistical assumptions are met exactly, but the importance and consequences of any violations should be understood.

The amount of time and effort required to conduct the pilot study will vary considerably depending on the hypothesis to be tested and the methods. In some instances the information collected during the pilot study can also be used as part of the monitoring information. Based on the assessment of the monitoring method in the pilot study the sampling regime should be confirmed and clearly articulated. Individual sampling protocols need to be finalised and a detailed procedure made available to all personnel involved. Standardisation between individuals can be critical. Information gained from the pilot study could be used to change both the hypothesis and the methods.

In some cases the pilot study will show that the chosen methods are not feasible. For example, consider the hypothetical cases given in Tables 3.2 to 3.4. In the first case automatic gauges may not be available or affordable; in the second aerial photography may not be regularly flown or made available in a timely manner; and in the third the necessary documents may not be readily available. Under these circumstances the very hypotheses and



methods may have to be changed or the programme even abandoned as being impracticable.

### 3.3.7 *Collect the samples*

Sampling should not commence before the methods and/or protocols have been established and staff trained or instructed accordingly. The rigour with which sampling is undertaken can influence the success or otherwise of the monitoring programme. Sampling details (e.g. replication, dimensions) should be based on statistical premises and checked during the pilot study. The agreed sampling protocols should be adhered to. Where this is not possible all variations should be carefully documented and this documentation kept with the data. The following documentation should accompany all samples:

- date and location,
- names of sampling staff,
- method used to collect the samples,
- number of samples required,
- equipment used to collect the samples,
- methods used for sample storage or transport,
- all changes to the established methods or protocols.

Sampling and data collection should be done in a manner to ensure the results can be used with confidence (i.e. were adequately replicated). Documentation of all practices is a vital part of demonstrating this confidence.

The effectiveness of a monitoring programme is also dependent on the timely processing of samples collected for further analysis (e.g. dissecting fish for chemical analysis of specific biological tissue). However, the need for rapid results should not compromise the processing of samples. If the processing is not sufficiently rapid, changes to the procedures may be necessary. Alternatively, the programme may need reassessment. Delays in processing the samples could also negate the usefulness of the programme. When the samples are processed, the following should be documented:

- date and location,
- names of processing staff,
- method used to process the samples,
- equipment used to process the samples,
- all changes to the established methods or protocols.

### 3.3.8 *Analyse the samples*

Many samples require analysis after they have been collected and processed. Whether this involves chemical analysis or biological identification, the means of having this done should be determined at the pilot study stage.

Statistical analysis is now regularly used to analyse data and ascertain the extent of any change or variation. These techniques should also be well and truly tested at the pilot study stage. There is little point in collecting and processing samples if the means of interpreting the data are not available. Collecting samples in the hope of finding the means to analyse them is not an effective strategy for a monitoring programme (it may be appropriate for a surveillance project). Achieving the objective of a monitoring programme is not possible unless the data from the samples is made available for interpretation. Valid statistical analysis is critical where complicated or contentious issues are being addressed (see Hewett 1986, Bishop 1983). Sample and data analysis should be done by rigorous and valid processes.

As with sample collection, a basic set of information should be documented when the samples are analysed:

- date and location,
- names of analytical staff,
- methods used for analysis,
- equipment used for analysis,
- means and location of storing data,
- all changes to the established methods,
- statistical tests and significance levels.

### 3.3.9 *Interpret data and report the results*

All monitoring information and results need to be interpreted and reported in a timely and cost effective manner. If this is not done the programme can be considered to have failed: monitoring is designed to provide results to assist further management. The interpretation should take place within the framework provided by the programme objective. Making the reporting schedule and the reports themselves publicly available is one way of ensuring that this critical aspect of the monitoring programme is given due attention.



Reporting can take many forms and it is not always necessary or even desirable to include all the results and detail, although these should be readily accessible. The form of the report will, in part, be determined by the nature of the problem and the monitoring objectives. Its express purpose is to ensure the monitoring data become part of the management planning process. In many instances it will also be useful for the report to comment on the need for further monitoring of the same nature or even of a different nature. The size and style of a report will vary according to the objective, the method used and the audience. Despite this variation in style, the report should be succinct and concise and supported by statistical analyses.

The report should indicate whether or not the hypothesis has been supported and whether management action is required. It should also be used to assess the effectiveness of the sampling methods.

### 3.3.10 Implement management and evaluate the project

The framework given in Table 3.1 and Figure 3.1 provides a series of steps that feedback into the planning process. Throughout the planning and implementation process for a monitoring programme these feedback steps should be used to ensure that the required rigour is being obtained and that the hypothesis can be tested by the data being collected. At the end of the programme, or after a predetermined time period, the entire process should be re-examined and necessary modifications made and recorded. Where the objectives have been met, the programme can be terminated.

## 3.4 Conclusion

Monitoring is an integral component of the management process. Poorly designed monitoring programmes are a liability and should be terminated and replaced as they can produce misleading and erroneous data or information. Given the difficulties of finding resources for management these should not be wasted on ineffective monitoring.

The framework given above does not attempt to provide a recipe for any particular monitoring programme. Rather, it provides a series of steps to assist people planning monitoring programmes make informed decisions about their particular needs. The feedback links in the framework are a means of ensuring that the adequacy of any programme is regularly reassessed.

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## 4 Identification of indicators

Patrick Grillas



### ABSTRACT

*Indicators are measurable variables for characteristics of an ecosystem. The number of parameters that can be used in a monitoring programme is enormous. The cost and the efficiency (indicative value, early detection) differs widely between indicators. The selection of indicators is therefore a critical stage in planning a monitoring programme. The identification of a clear refutable hypothesis is a necessary preliminary stage to the selection of indicators. They are then selected according to the question (the problem or issue) aiming at the best compromise between a clear early answer to the initial question, costs and feasibility.*

*Physical indicators are more likely to give early warning because they are usually closer to processes which are potentially damaging to the ecosystem: e.g. wetland loss, eutrophication, pollution by toxic substances, alteration of the water regime. Unfortunately they can be costly and their impact on the biological components of the ecosystem may be difficult to assess. Biological indicators can be monitored both for their own interest and their indicative value. They provide information on the impact of processes on the living organisms. Bioaccumulator species can provide a cheaper tool to measure concentration and availability of toxic substances in the environment. However biological indicators also have a number of limitations including mobility, late warning and buffered answer.*

*Indicators are proposed for specific threats to Mediterranean wetlands (wetland loss, changes in water regime, eutrophication, pollution by toxic compounds, harmful exploitation). In any case, the proposed indicators are not suggested to be pertinent in all situations, but rather aim to illustrate how the selection of indicators can be achieved among the wide array of possibilities.*



## 4.1 Introduction

The ultimate aim of monitoring wetlands is to assess the changes in the ecological character (see chapter 2 in this volume) that may occur in these ecosystems (these changes being natural or man-induced, resulting from on-site or off-site management) and to be able to set hypotheses on the causes of these changes (stresses). Stresses have effects on ecosystems that are expressed in different ways at the different levels of organisation (e.g. Odum 1985).

Crucial steps in the process of establishing a monitoring programme are presented in chapter 3 (Finlayson, this volume). The objectives of the monitoring are established on the basis of Goldsmith (1991) and Keddy *et al.* (1993):

1. the clear definition of the "pristine" or "optimum" state of the ecosystem;
2. the identification of the variables (indicators) which indicate the state of the ecosystem;
3. the levels of these variables which indicate acceptable conditions and/or departure from these conditions (i.e. which separate "environmental noise" due to natural fluctuations from man-induced ecological change); and finally
4. the assessment of the results of management.

However, as highlighted in chapter 3 (Finlayson, this volume), once the objectives of the monitoring have been established, the identification of refutable hypotheses for future changes in the ecological character of the wetland is a very important step which will facilitate the choice of the indicator.

The choice of indicators among the huge array of possible variables is probably one of the most important decisions to be taken in the process of establishing a monitoring programme. Selection of indicators on a sound basis would be a reasonably easy task if predictive operational models of wetlands existed. Unfortunately we do not know what in an ecosystem are the key variables (state variables) that describe its quality and the level of stress to which it is submitted (Rapport *et al.* 1985).

Selection of indicators is a compromise between the "best" monitoring programme one can set up from

actual knowledge of the ecology of the considered ecosystem (which is usually far too expensive in time and equipment) and the available resources. This compromise is temporary as the threats upon an ecosystem and resources can change over time, and the knowledge of the functioning of the ecosystem increases with accumulated data and studies. Indicators have to be selected in each site according to the objectives of the monitoring programme, the type of ecological change, the type of wetland, the scale of space, the scale of time, the information available and resources available.

The selection of indicators does not constitute an isolated step in the process of planning a monitoring programme. Planning a monitoring programme is an iterative process (see figure 3.1 in chapter 3) where the selection of indicators is dependent on the other steps. A crucial step is first to decide what has to be indicated; e.g. biodiversity (including populations of target individual species), erosion rate, level of stress imposed by specific pollutants, etc. The definition of precise objectives in the monitoring programme is of paramount importance in the selection of indicators.

The objective of this chapter is to provide some guidelines in the process of selection of indicators. The number of situations (type of wetland  $\times$  type of ecological change) and the number of potential indicators are enormous and cannot be presented or discussed thoroughly here. However some categories of indicators can be recognised which apply to certain situations (i.e. certain types of wetlands, particular threats, etc.). The more specific the indicators, the more useful they are.

The approach is pragmatic in that the aim is to help the users, in particular wetland managers, in selecting their own indicators according to their local needs and resources and in listing some indicators (or group of indicators) which are important in Mediterranean wetlands. In no way is the proposed list of indicators complete or appropriate for all situations, but the process of selection of indicators should apply. The proposed process relies upon the functional analysis of the wetland and the underlying assumption that biological diversity and individual species will persist if quality of habitat is maintained. In most instances the selection of indicators should first address the key environmental factors which control the habitat structure and production. In Mediterranean wetlands water levels, nutrients and



salinity are the most frequent proximate factors that control species composition, diversity structure and production of plant communities, and in turn the use made by wildlife and people.

## 4.2 What is an indicator?

*Indicators* are measurable variables for characteristics of an ecosystem (wetland) that are assumed to be of importance for its value, and their magnitude indicates divergence from a certain environmental objective. Kushlan (1993a) suggests that the theoretical basis of indicators derives from the general systems theory (Von Bertalanffy 1968, Odum 1983) which proposes that the condition of a system (including ecosystem) should be predictable from the status of state variables and processes connecting them. Three categories of variables can be recognised in ecosystems (Noss 1990) that can be affected by a stress: compositional, structural and functional. Indicators can measure functional, structural or compositional attributes of the system whatever the scale considered:

- compositional indicators involve types of landscape, communities, populations, species, infra-specific items existing in an ecosystem.
- structural indicators describe the physical assemblage of the elements in the system: landscape, habitat, species, population, genetic variation, etc.
- functional indicators describe processes in the ecosystem: water regime, nutrient cycling, inter-specific interactions, gene flow, fluxes of material, etc.

Both physical and biological variables can constitute valuable indicators. A plethora of possible indicators exist and have been used, from infra-cellular to landscape level, in monitoring ecosystems. Almost every variable or species can be an indicator of the state of any system/wetland. However, the amount of information provided and the cost can differ widely according to the variable/species considered, the wetland, the problem in question, etc.

Although this is not often adequately considered, cheap and valuable indicators can be found off-site from governmental and non-governmental agencies

particularly those concerning the catchment area of the study site (land use, meteorological data, pumping stations, irrigation and drainage schemes, industrial plants, population density, etc.).

### 4.2.1 Physical and biological indicators

A monitoring programme can include non-biological (water level, concentrations of nutrients or other ions, temperature, irradiance, etc.) and/or biological (at various levels, from sub-cellular to individual, species, population, whole community) variables. The simultaneous use of biological and non-biological variables permits the testing of hypotheses on the causes of the observed changes.

#### Physical indicators

Physical indicators provide precise information on the management implemented and on selected possible causes of stress (wetland surface area, water fluxes, sediment, pollutants, etc.). Usually a few physical variables are crucial (key environmental indicators) and sometimes very easy to measure (e.g. water level, salinity, suspended solids). Important physical indicators in wetlands are related to the nutrient cycles and pollution issues.

Many physical indicators are very specific to particular threats and they must be selected according to the type of wetland and the threats that are most likely to occur (it would be very expensive to monitor all possible pollutants). Measurement of some pollutants at very low concentrations can be complex and expensive (e.g. heavy metals). Furthermore, knowledge of the level of specific pollutants in wetlands does not allow for a precise assessment of their availability and impact on the biological systems.

#### Biological indicators

The range of biological indicators that can be used for monitoring is enormous, from landscape to molecular level and a considerable number of papers have been and are currently being published on this issue. Besides their indicative value, bio-indicators may have an intrinsic value, as objectives of the management (conservation value), as a pest or for its economic value (resource). There are three motivating reasons for monitoring a species



(Keddy 1991): because the species is of special interest (1) for its rarity (e.g. *Gentiana pneumonanthe* in Mediterranean wetlands; Dalmatian pelican *Pelecanus crispus*), (2) because it is undesirable (e.g. undesirable, often alien species like *Ludwigia grandiflora*, ruddy duck *Oxyura jamaicensis*) or (3) because it is an indicator of environmental conditions (e.g. common reed *Phragmites australis* which indicates the hydrological condition and shapes the habitat for wildlife). Species are not uniformly distributed but rather respond to the heterogeneity of the physical conditions (climate, altitude, substrate, water depth, etc.) and interactions between species. Each species has particular requirements for its environment, these requirements being more or less narrow or broad (ubiquitous species). In plant ecology, plant species are used for the identification of communities or habitats. The use of biological organisms as indicators of the state of an ecosystem exploits the information that the presence and absence of selected organisms gives about the environmental conditions (i.e. the environmental conditions prevailing are in the range tolerated by the organisms that are present).

To be effective for monitoring, a potential bio-indicator should possess a number of desirable attributes, presented in box 4.1.

#### BOX 4.1 Desirable attributes of bio-indicators (Hellowell 1986)

1. are readily identified – taxonomic uncertainties can confuse data interpretation;
2. may be sampled easily, that is, without the need for several operators or expensive equipment, and quantitatively;
3. have cosmopolitan distribution – the absence of species with very narrow ecological requirements and limited distribution may not be associated with pollution, etc.;
4. are associated with abundant autecological requirements – this is of considerable assistance in analysing survey results and devising pollution, or biotic indices;
5. have economic importance as a resource or nuisance or pest; species which are economically important (fish) or are a nuisance (some algae) have intrinsic interest;
6. readily accumulate pollutants – especially so as to reflect environmental levels since this facilitates understanding of their distribution in relation to pollution levels;
7. are easily cultured in the laboratory, which also assists in relating experimental studies of their responses to pollutants and field observations;
8. have low variability, both genetic and in their role (niche) in the biological community.

#### 4.2.2 Indicators and accumulators

An organism can indicate the level of stress (e.g. pollution) in two different ways: as an *indicator* or as an *accumulator*.

##### Indicative bio-indicators

The presence of a particular species in a habitat indicates that the level of pollution of this habitat is in the range of tolerance for that species. The indicator can be elaborated as a presence/absence index which provides a very rough estimation of the level of stress and can detect only acute problems. More sensitive indicators of physiological stress have been developed with sub-lethal biological endpoints (growth rate, reproductive output, morphogenetic, etc.).

The information supplied by a bio-indicator varies widely according to the level of organisation at which it is found (see box 4.2) and with the effects of the stressor (Kushlan 1993a, 1993b; Hellowell 1986). Indicators at the landscape or ecosystem levels are highly integrative but are not very effective as early warning indicators, and the identity of the stressor may remain obscure.

#### BOX 4.2 Potential bio-indicators for wetlands at various levels of biological organisation (adapted from Kushlan 1993b)

Level	Indicator types
1. Suborganism	molecular, physiological, histopathological, immunological, xenobiotic burden (all taxonomic levels; plants, invertebrates, fish, etc.)
2. Organism	growth, death, behaviour, toxicological studies (e.g. LD50, much used on fish for toxicological studies)
3. Population	presence/absence, distribution, population size, reproductive success (all taxonomic levels)
4. Community	species assemblage, species richness, diversity indices
5. Ecosystem	energy and material flow, state variables



Valuable bio-indicators can be found at the sub-organism level (anatomical, physiological, molecular) where they constitute early warning indicators. They demonstrate exposure to a stressor before their adverse effect can be identified at the individual or population level (Huggett *et al.* 1992, Zakharov & Clarke 1993). However, many of these indicators are not easily monitored by a wetland manager (e.g. DNA alterations, activity of enzymes, antibody production, etc.) and it is still more a research field than routine measurement.

Species composition, species diversity and abundance have been extensively used for monitoring disturbance and recovery of ecosystems. Although the data are usually available for some groups of plants or animals, their use as sensitive monitoring indicators should be assessed carefully. Proper monitoring requires a range of indicators from different levels of organisation (e.g. vegetation, invertebrates, amphibians and fish) integrated to a common objective with an adequate sampling procedure. It is also necessary to be able to separate the respective effects of ecological change from those of environmental fluctuations (e.g. natural climatic fluctuations) or external changes (particularly for non-sedentary organisms). Lumping a motley set of population monitoring studies does not constitute in any way an acceptable ecosystem monitoring programme.

### Accumulative bio-indicators

An organism can accumulate substances in its tissues (bio-accumulator) and therefore indicate an environmental level or the extent to which the organism has been exposed to that substance. Bio-accumulators are very useful when they concentrate substances which occur at very low level in the environment, where they are difficult to detect. They are also very useful in the case of pulse pollution where organisms are subjected to irregular peaks of toxic substances (e.g. accumulative indicators for heavy metals). Bio-accumulative indicators have been used particularly in the monitoring of pollution by metals and pesticides, especially organochlorine insecticides. The better known examples for birds are probably the impact of organochlorines on the peregrine falcon *Falco peregrinus* (Moore & Ratcliffe 1965) and on the brown pelican *Pelecanus occidentalis* in the US (Jehl 1973).

#### BOX 4.3 Attributes of an ideal bio-accumulative indicator (from Hellawell 1986)

1. All individuals of the indicator species should exhibit the same simple correlation between their residue content and the average pollutant concentration in environments (water, sediment, food) at all locations and under all conditions.
2. The species should accumulate the pollutant without being killed by the maximum level encountered in the environments.
3. The species should be sedentary in order to be sure that the findings relate to the area of study.
4. The species should be abundant throughout the study area (and preferably have a widespread distribution in order to facilitate comparisons between areas)
5. The species should be long-lived enabling sampling of several age classes and assessing long-term effects.
6. The species should be of large size to provide sufficient tissues for analysis.
7. The species should be easy to sample and robust for surviving in laboratory conditions.

Phillips (1977) and Hellawell (1986) have described seven desirable attributes of an ideal accumulative bio-indicator (see box 4.3). Valuable accumulating bio-indicators should also be large enough to supply adequate tissues for analysis, be sedentary to reflect local conditions and be robust to survive laboratory conditions (Phillips 1977). Such an ideal indicator does not exist but these attributes underline the problems that are encountered in the field. Among factors that affect reliability of indicators are changes in the rates of accumulation and excretion of the pollutants, age, size and physiological condition of the indicator species, the trophic level of the indicator species, environmental variables that affect solubility and rate of uptake, and interference between substances (Hellawell 1986).

### 4.3 Selection of indicators

The first dichotomy in the objectives of a monitoring programme is whether it addresses wetland surface area or wetland quality. Wetland area primarily concerns habitat losses and habitat transformation issues (surface area of wetlands and per habitat), either man-induced or natural. In contrast, problems dealing with the biological, and the physical and chemical characteristics of the ecosystem are grouped into wetland quality.



Changes in ecological character of the wetland, and in turn the indicators, can be very diverse. Ecological change results from either: (1) the impact of management (e.g. success of restoration or management plan implemented); (2) external, more or less localised, threats (e.g. pollution, water extraction, etc.); or (3) generalised external trends (e.g. climatic). In all situations the objectives of the monitoring programme will be to recognise early that changes are occurring (requires a baseline or a control), to measure the extent of changes, the causes and ultimately to identify measures to stop or reverse adverse changes.

When monitoring addresses the impact of management on wetlands, the indicators to be selected are relatively easy to identify. They should be as closely related as possible to the physical or biotic changes brought about by management implementation and should concern the different compartments (abiotic, flora, fauna) of the ecosystem at different levels of organisation. The most frequent changes introduced by management involve water management (duration, period of flooding, height of water), grazing (removal, introduction, changes in grazing pressure, species or breed), harvest of plants or animals, disturbance, etc.

Although ecological change and external threats can be very diverse, some types are much more likely to occur than others. Besides destruction or drastic physical alteration which are covered in the next section, the most frequent and important changes that threaten Mediterranean wetlands are: (1) alteration of water regime; (2) eutrophication; (3) pollution by non-biogenic elements; (4) over-exploitation of natural resources (grazing, hunting, fishing, thatching, etc.); and (5) introduction of alien species.

### Biotic indices

The presence of each species in a given wetland provides a piece of information on the ecological situation and the level of stress that the ecosystems receive. This information is difficult to analyse and interpret when species are numerous and series of data are involved. The aim of biotic indices is to summarise the information that is contained in the species list or the relative or absolute abundance of the species found. Indices can be calculated on the

abundance of selected taxa, on the structure (species richness, diversity) of assemblages of species (phytoplankton, invertebrates, etc.) or comparing different communities or species assemblages. Indices calculated on the abundance of species are primarily useful for monitoring eutrophication, and structure indices are used to evaluate the level of stress received by an ecosystem by measuring deviation from a theoretical structure (e.g. Fisher *et al.*, 1943, Preston 1948, MacArthur 1957). It is possible for a wetland manager to establish a monitoring programme based on biotic indices that will provide a global assessment of the stress that an ecosystem receives. These indicators have to be found at a relatively high level of organisation (population, community, ecosystem) and will consequently not provide early warning. Great care should be given to statistical treatments applied to indices.

The following sections present different parameters that can be used as indicators, grouped according to the type of change. A short description is provided for each indicator together with some comments on its advantages and disadvantages. The indicator parameters appear as ***bold italic*** in the text.

#### 4.3.1 Changes in wetland area

Monitoring wetland losses or gains requires a clear and operational definition of wetland. The definition itself does not make any difference to the process, as long as it is consistent over time and enables the wetland to be delineated. Monitoring change in wetland area can be achieved through repeated inventories, including mapping, on the same sites (see MedWet methodology for wetland inventory in Costa *et al.* 1996) every 5–10 years. However, the objectives of the monitoring programme do not usually necessitate a complete inventory of the wetland but rather to assess changes. Therefore monitoring can be achieved through a more limited number of indicators than used in an inventory.

A number of indicators can be used at different levels:

- A compositional indicator of a wetland can be the ***list of different habitats*** it includes (e.g. temporary marshes, lagoons, wet meadows, etc.). Possible lists of habitats are the Habitat



Description System proposed for MedWet inventories (Farinha *et al.* 1996) or the European Union CORINE biotopes classification (European Communities Commission 1991, Devillers & Devillers-Terschuren 1993). Compositional indicators do not provide any information on quantitative changes in wetland area.

- **Habitat patchiness, surface area per habitat, fragmentation, river length** are but a few possible indicators of the structure of the site.
- **Trend** analysis reveals the rate of wetland loss or gain. Rates of wetland loss or gain can be analysed over time (e.g. Frayer *et al.* 1983a, Hollis 1992) and/or compared with other regions, or trends (e.g. surface area cultivated: Lemaire *et al.* 1987, Baldock 1989).

Besides proximate indicators like those mentioned above, indicators should be selected off-site or at different levels of organisation in order to understand the causes of wetland loss. These indicators vary according to the situation. For example, the possible causes of change and in turn possible indicators can be the land use in the wetland and/or in the catchment area, canalization of rivers, embankment, erosion/accretion rates, subsidence rates, etc.

At a national or regional scale complete inventories of wetlands cannot usually be achieved at a sufficient frequency (5–10 years). Repeated surveys of selected sites cannot be representative of the whole area (selection of sites: large sites are usually selected, as well as those important for flagship species like birds, etc.) and do not allow statistical analysis of trends (samples are not independent). Monitoring should therefore be achieved with a protocol including (stratified) random sampling of wetlands (Frayer *et al.* 1983a & b, Ernst *et al.* 1995). Repeated surveys require a clear and practical definition of wetlands that enables consistent delineation by field technicians, as well as a standard classification.

Tools for monitoring wetland loss are primarily remote sensing by aerial photographs (balloons, aircraft, ultra-lite planes, etc.) or satellite imagery. For delineation and survey of wetlands,

infrared aerial photographs (circa 1:20,000 scale) appear to be the most accurate tool (Anonymous 1992, Taylor *et al.* 1995). Satellite images are useful for large areas, when aerial photographs are not available and/or when less precise delineation is needed. The use of radar is still at the developmental stage but could in future, in combination with optical sensors, improve results obtained by satellite data (Holmes 1992). When feasible, the information can be organised in a Geographic Information System (GIS). This technique is particularly suitable for comprehensive storage of data at different geographical scales and permits cross-analysis of data (Cluis 1992). Data analyses include time series analysis, spatial statistics, etc.

#### 4.3.2 Changes in water regime

In most instances changes in the water regime result from human impact and concerns a reduction of water level, duration of flooding, etc. due to over-exploitation of the water resources in the wetland or upstream (see chapter 2, this volume). Conversely, management can also lead to increasing the water level or duration of flooding in wetlands or to changes in the periodicity or amplitude of water levels, e.g. Lake Kerkini, Greece (Crivelli *et al.* 1995), Camargue, France (Tamisier & Grillas 1994). In some cases changes in water management induce changes in water salinity without much change in water level, e.g. freshwater diversion at lake Ichkeul, Tunisia, where water level is partly controlled by sea-level.

Changes in the water regime may also occur due to natural processes. Drying out of aquatic ecosystems (land elevation by organic accumulation) is a slow process whose rate increases with eutrophication. Another example of a natural process is the lowering of karstic lakes due to geological processes, e.g. Megali Prespa in Western Greece.

In all situations great care should be taken in separating natural from human-induced changes (management), and fluctuations from trends. The very large fluctuations in rainfall that are characteristic of the Mediterranean region lead to wide changes in water regime of wetlands irrespective of any anthropogenic change. On a different time scale, climatic change and sea level rise may alter existing hydrological conditions. It



is essential to establish a baseline of the extent of natural fluctuations before assessing changes.

Indicators of changes in the water regime of a wetland are quite straightforward. On-site, the water level and the quantities of water entering the wetlands (rainfall, rivers, canals, etc.) should be measured, or for rivers the flow or height of water. The minimum monitoring programme should measure directly the **level of surface and groundwater**. Surface water level should be measured in all wetlands as the basic environmental factor that controls habitat and species distribution. Water level data are often lacking, thereby impeding any ecological assessment. Off-site and/or on-site, valuable data can often be obtained from the agencies responsible for the rivers, lakes or other wetland types. Water levels in dams and rivers are usually measured daily over a very long time and give information of changes upstream.

The measurement of the **water balance** or **water budget** (quantities entering or leaving the wetlands) enables a better understanding of the causes of changes (or at least to set hypotheses). The main sources of water are usually rainfall, rivers, canals or groundwater (see Mitsch & Gosselink 1993). These variables can be measured very easily at a very low cost as long as staff remain on site. Data recorders improve efficiency when resources permit.

Additional relevant information can be drawn from **salinity** measurement of surface and below-ground water in littoral and endorheic wetlands. Salinity measurement (or equivalent: **electric conductivity** of water) may constitute an indicator of water fluxes through dilution or concentration effects. For example when water recedes in a marsh, salinity measurement of water allows for an estimate of losses through evapotranspiration or infiltration. Similarly in lagoons, water salinity is an indicator of the water budget from the different compartments (rainfall, sea, rivers, etc.), i.e. hydrological processes. In certain cases, **water temperature** can be an indicator of changes in the water regime, e.g. in wetlands fed by springs at a very different temperature to surface waters.

Plant, invertebrate or fish species can constitute bio-indicators of the water regime of wetlands. However, these bio-indicators cannot be recommended for monitoring because direct measurement of the physical conditions is easier,

cheaper and brings more information on the wetland water regime. This method should be restricted to sites where no continuous monitoring can take place. A single species of plant may not constitute a good indicator, but the **ratio of annual/perennial species** is an indicator of the intensity of stress. Similarly, the **respective number of terrestrial, amphibious and aquatic plant species** is an indicator of the prevailing water conditions. **Large conspicuous species of invertebrates** (phyllopods) or the **zooplankton** indicate isolated temporary marshes with no connection to large sites containing fish (Pont *et al.* 1991). Conversely **fish species** can indicate permanence of water over the year or the temporary or permanent connection between waterbodies, e.g. between lagoons, sea and/or rivers.

#### 4.3.3 Changes in water quality: eutrophication

The main biogenic pollutants that threaten wetlands are nitrogen and phosphorus. They both increase the natural trend towards eutrophication. The first phase of eutrophication is characterised by an increased primary (plant) production of rooted, floating or planktonic plants. Hyper-eutrophication is characterised by massive algal blooms responsible for the destruction of rooted vegetation, often followed by loss of oxygen in the water column and sediment when the high biomasses of algae die. The immediate consequence of this lack of oxygen is the more or less complete eradication of animal life in all or part of the wetland (fish may escape while poorly mobile benthic invertebrates die). The consequences of eutrophication, and therefore the indicators, vary according to the type of wetlands, the origin of pollution and local causes. However, common features can be recognised and differences will be highlighted when necessary.

The best measure of eutrophication is to establish the **nutrient budget** (the quantities of nutrients entering and leaving the wetland), and to measure the amounts and fluxes of nitrogen and phosphorus between the different compartments (water, oxidised sediment, anoxic (reduced) sediment, plants, etc.). The most important nutrient sources are rivers, point sources (e.g. outflow of water treatment plant) and either agricultural or urban non-point sources. Other

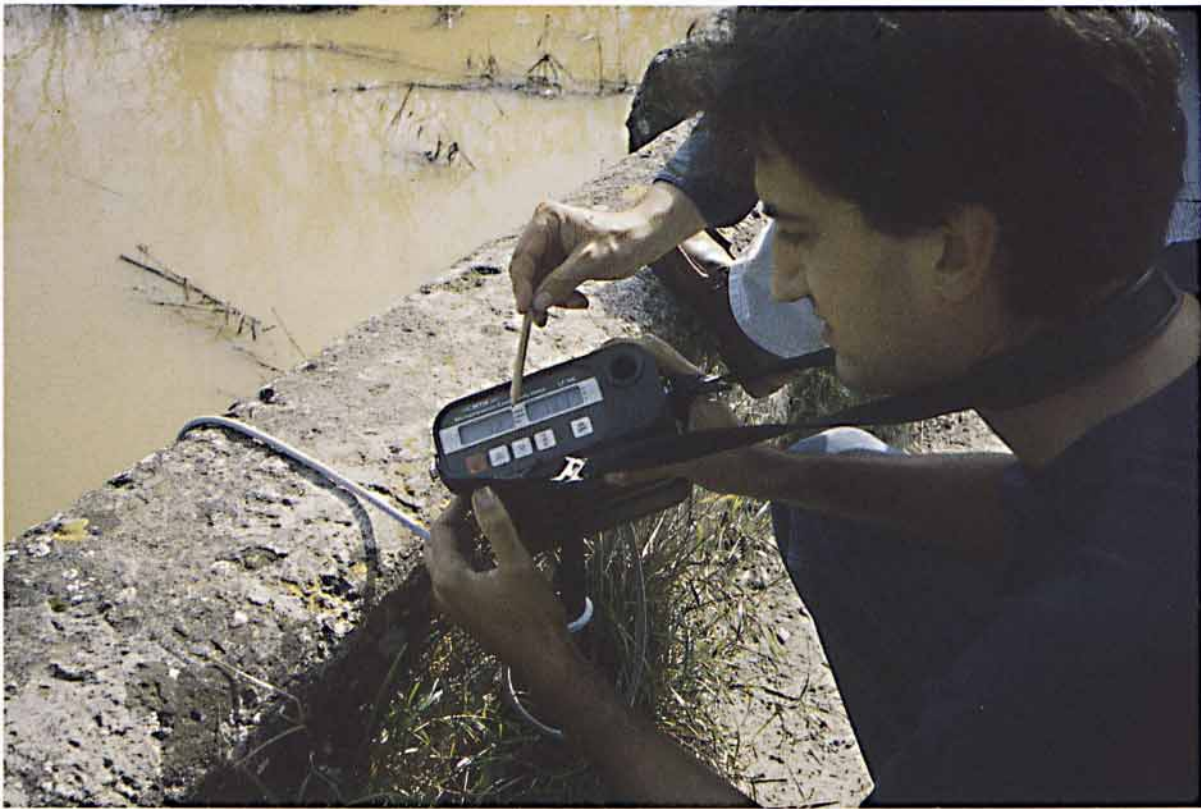


Plate 4.1 Water salinity can be monitored using an electronic conductivity meter. (Nick Riddiford)

sources of nutrients are usually less important (airborne, below-ground water) but their potential importance should be assessed locally. The relative importance of nitrogen and phosphorus and their chemical forms ( $\text{NH}_3$ ,  $\text{NO}_3$ ,  $\text{NO}_2$ ,  $\text{PO}_4$ ) vary according to the source of pollution. The nutrient budget is complex and cannot usually be calculated through monitoring. However, when a limited number of sources are responsible for most of the nutrient inputs, they can be monitored more intensively.

### Nutrients in the water

In deep lakes and rivers the **concentrations of nutrients in the water** are valuable indicators of the trophic level. In deep lakes a correlation is usually found between phytoplankton biomass and ortho-P concentration (e.g. Vollenweider 1968, Pourriot & Meybeck 1995). In contrast, the concentration of nutrients in the water is not a good indicator of the trophic level of coastal lagoons, marshes and shallow lakes because (1) most of the stock is usually in sediment, (2) rapid changes in nutrient concentrations occur in the

water column due to uptake by plants and exchanges with sediment (e.g. wind-induced resuspension of sediment, fluxes of phosphorus from the sediment to the water column as a result of a decrease in the redox of sediment, etc.). However, levels of nutrients in the water entering the wetland is a key variable in establishing the nutrient budget. Nutrients in the water need to be measured over a 12 month cycle; frequency of measurement can eventually be reduced when the seasonal pattern is well known. Nitrate levels generally exhibit a maximum in winter, probably due to low rates of photosynthesis and denitrification.

### Indicators in the sediment

The **concentrations of nutrients in the sediment** are good indicators of the total amount stored (ultimately to plant production) in marshes, lagoons and shallow lakes. The most used indicators are **total phosphorus** and **total nitrogen** which are primarily involved in anthropogenic eutrophication. Concentrations of nutrients over the annual cycle vary less in sediment than in



water and no constant pattern can be recognised in different sites (Laporte 1979, Sfriso *et al.* 1988 for lagoons) and nutrients.

The depth of sediment considered is important and should be clearly indicated, nutrient profiles in the sediment differing widely between sites or even in some cases within the annual cycle. The depth of sediment analysed should be chosen according to the objectives and the issues (problems) to deal with. Submerged plants are often superficially rooted and 10 cm depth is sufficient for analyses. The depth can be greater for large amphibious plants (e.g. *Phragmites*) and samples may prove useful up to 0.5 m or even deeper. When large depths are involved it is better to sample the sediment at different (discrete) depths instead of mixing the complete profile. Analysing the sediment at different depths may provide additional information on the processes involved in nutrient accumulation or the bio-geochemical cycles. Top sediment can be subjected to partial depletion through exchanges with the water column and uptake by plants, or conversely can be richer in nutrients resulting from recent increases in the nutrient load. **Nutrient profiles** in the sediment can be an indicator of the rate of eutrophication over time.

**Redox potential** is an indicator of the amount of organic matter and of the degradation processes in the sediment. The redox potential value depends on a number of complex bio-geochemical processes and indicates the availability of oxygen and associated chemical changes in the sediment. Low values of redox (< -0.2V at pH 7, Brooking 1988) in marine-originated sediment indicates the presence of compounds in the sediment ( $\text{Fe}^{2+}$ ,  $\text{S}^{2-}$ ) that are toxic to plants (Koch & Mendelsohn 1989; Van Wijck *et al.* 1992). Redox potentials vary little over an annual cycle but change with water velocity and sediment particle size composition (which in turn depends on the situation within the lagoon according to circulation of water, sources of nutrients and places of preferential sedimentation). Redox potential also varies with depth, the pattern changing with the trophic situation (CEMAGREF-IARE 1994).

### Indicators in the water column

Reduction of **water transparency** is often a side effect of eutrophication resulting from light

attenuation by algae and/or by fine particles. In coastal lagoons, bays and estuaries, light availability is the most important factor regulating the distribution and abundance of submerged aquatic rooted macrophytes (Zimmerman *et al.* 1994). A very simple measure of light attenuation is the measure of the water depth at which a standard black and white disk disappears from an observer at the surface (Secchi disk). This gives an estimate of the depth at which light is sufficient for growth of submerged rooted plants. Measurements must be repeated frequently because it is sensitive to very dynamic factors like the abundance of phytoplankton and suspended solids. More sophisticated and more precise measurement of water transparency can be performed with light sensors to measure light profiles in the water or continuous light budget (if connected to a data logger).

**Oxygen concentration** and **pH** are good indicators of primary production provided they are recorded over a 24 hour period. High production results in an increase in oxygen concentration and pH in water at midday; high biomass of plants leads to a strong decline of oxygen concentration during the night.

### Microphytes

**Planktonic, epiphytic and benthic algae** are useful as indicators in eutrophication studies (see review in Hellawell 1986, Shortreed *et al.* 1984, Cattaneo 1987). Important indicators are **density** (no. cells/ml), **size structure, biomass (chlorophyll), production, species composition** and **diversity** (relative abundance of different groups) which are sensitive to nutrient levels, water circulation, salinity, etc. However, the very high variability of biomass and production over time and space makes it difficult to establish the baseline and requires very high frequency of sampling (weekly) and a large number of sampling sites (CEMAGREF-IARE 1994).

**Density, biomass, chlorophyll, species composition** and **diversity** of the phytoplankton or periphyton community constitute bio-indicators of the trophic level in lakes, lagoons, rivers. Standardised quantitative sampling of benthic and epiphytic algae is difficult (Cattaneo *et al.* 1995) and requires the use of artificial substrates (e.g. glass slides, see Hellawell 1986). The silica



skeleton (frustule) of diatoms remaining in sediment allows an analysis of species composition over long periods of time (Stevenson & Battarbee 1991, used at Ichkeul, Prespa, etc.). In lagoons it is not always easy to separate the causes of changes in the species composition of phytoplankton between the effects of nutrient input and freshwater inflow, both having strong effects on species composition and often occurring simultaneously.

These bio-indicators require high expertise in taxonomy and are costly in time (cell counts).

### Macrophytes

In contrast, macrophytes (**angiosperms and macro-algae**) are easy to identify, exhibit much less short-term variability and constitute valuable indicators of the hydrodynamics, substrate and light conditions (turbidity) (CEMAGREF-IARE 1994). Macrophytes are considered valuable indicators in rivers (Haslam 1982, Klosowski 1985, Haslam 1987, Carbenier *et al.* 1990). In Mediterranean rivers the response of macrophytes to environmental conditions is poorly documented (Ferrer & Comín 1979, Romero & Onaindia 1995) and regional baselines must be established integrating slopes, current velocity and geology.

**Species composition, diversity and production** (or biomass) of the different species and groups of macrophytes are affected by eutrophication. Interpretation must be made with care as increased biomass of rooted macrophytes can result from a seasonal effect, increased nutrient inputs (early stage) or recovery from a more severe eutrophication stage.

Eutrophication has direct and indirect consequences on light attenuation and substrate (sedimentation of organic matter), and in turn on macrophytes. **The maximum depth of colonisation** of submerged rooted macrophytes (different for each species) is correlated with the light attenuation and constitutes an indicator of the light budget at the bottom of lakes, lagoons and the sea during the growing season. This variable is not only sensitive to eutrophication but also changes over time with water depth or any factor that might affect water transparency (e.g. suspended solids, salinity, density of filtering organisms like mussels or oysters).

In lagoons, during the process of eutrophication, rooted macrophytes (*Angiospermae*: *Cymodocea*, *Zostera*, *Potamogeton*, etc.) disappear first, replaced by *Rhodophyceae*, themselves replaced by *Chlorophyceae*. Among this last group the most nitrophilous species dominate (*Enteromorpha*, *Ulva*). At lower salinity *Ruppia* and *Potamogeton pectinatus* are the most tolerant to eutrophication. Valuable indicators can be found in the **biomass or frequency of the different groups** (*Angiospermae*, *Rhodophyceae*, *Chlorophyceae*). Advanced stages of eutrophication in lakes, rivers, lagoons and shallow marine bays are often characterised by a dense **covering of floating macro-algae**.

In lakes and freshwater wetlands, eutrophication favours species with a high growth form (access to light: emergent, floating-leaves) or submerged species with low light requirements (e.g. *Ceratophyllum*).

### Macro-invertebrates

**Macro-invertebrates** constitute a widely used assemblage of species in pollution assessment and monitoring, particularly in rivers where a number of indices have been proposed (for a review, e.g. Hellawell 1986, Spellerberg 1991, Pourriot & Meybeck 1995). **Chironomids** and **molluscs** have been extensively used for the classification of the trophic levels of lakes. The species number is very large which produces a diversity of indicators and responses but, as a result raises taxonomic difficulties for certain groups (e.g. chironomid larvae). High variability in space and time requires a high number of samples and in turn time-consuming analysis. These difficulties can partly be overcome by appropriate techniques (family level analysis, sampling strategy), improving the cost-benefit ratio of the analysis. In lagoons, distribution and abundance of species/groups are correlated with salinity and temperature fluctuations, circulation of water and organic deposits (e.g. Guelorget & Perthuisot 1984, Whitlatch 1981). In lagoons, macro-invertebrates are submitted to important stresses which make it difficult to identify symptoms of an additional stress (e.g. pollution effects). In contrast in the sea, where physical conditions are stable, more macro-invertebrates constitute valuable bio-indicators of the pollution level, including early warning species (Bellan 1976, 1991; Salen-Picard 1993) if the baseline has been



Plate 4.2 Sampling aquatic invertebrates as indicators of water quality. (Nick Riddiford)

established (e.g. Peres & Picard 1958, 1964). Methodologies have been proposed to rigorously identify valuable indicators in different regions (e.g. Gray & Pearson 1982).

## Vertebrates

**Vertebrates** are usually poor indicators of the trophic conditions of a wetland. Although they are sensitive to various levels of pollution, they constitute late indicators of organic pollution. Furthermore, because they are highly mobile, they tend to escape (in open systems like lagoons) when conditions deteriorate. However the **species composition of the fish communities** can be indicative of the trophic level of lakes, rivers or lagoons (Crivelli 1992).

### 4.3.4 Changes in water quality: pollution by toxic substances

Toxic substances that eventually affect wetlands are mainly products (or their residues) which are manufactured for use in agriculture or mosquito control, such as pesticides, or by-products of a range

of industrial activities. The toxic substances produced by human activity have changed considerably over time and thousands of chemicals are currently being produced and may eventually enter wetlands (Hellowell 1986). The most important non-biogenic pollutants occurring in Mediterranean wetlands are pesticides of various kinds (organohalogenes, organophosphorus, etc.), heavy metals, detergents and hydrocarbons of petroleum. Radionuclides are not currently known to be an acute threat for wetlands in the Mediterranean region.

Besides medical effects that are not in the scope of this guide, non-biogenic pollutants can have a very severe deleterious impact on the wetland ecosystems from the infra-cellular level of organisms up to the ecosystem level (Gilbertson *et al.* 1977, Morgan 1979, Root 1990, McCarthy & Shugart 1990, Fox *et al.* 1991, Zakharov & Clarke 1993, Kushlan 1993a, 1993b). In addition to pollutants which are very toxic, attention must be paid to substances which tend to accumulate in organisms or to persist in the ecosystem. The responses of organisms to toxic compounds are complex, determined by factors such as the nature and the concentration of the substance, the duration of exposure, the sensitivity



of the organism and the concentration of other toxic substances. To overcome this problem, a number of standardised toxicity tests have been developed for the most frequent toxic substances. The laboratory conditions needed for these toxicity tests means that extrapolation of the results to field conditions is not easy. Furthermore these tests have been developed for each toxic substance in isolation and the combined effects of several toxic substances are often not known (CECPI 1981).

More recently, tests have been developed on complete effluents rather than on individual chemicals. They can be used for testing mixtures of pollutants at different concentrations on a suite of organisms which should be chosen from different trophic levels. They do not provide information on long-term effects and are only relevant for that situation.

Monitoring pollution by toxic substances can be achieved either by direct measurement of the concentration in the ecosystem (e.g. in the sediment, in water, etc.) or by measuring bio-indicators. Both approaches have their advantages and limits.

### Direct measurement of concentration of toxic substances

The most direct method for monitoring pollution by non-biogenic pollutants would be to measure the fluxes and the fate of the various pollutants. This is not feasible for many reasons including the diversity of pollutants and their various forms, the multiple sources of pollution associated with very different fluxes and, not least, the cost. Chemical monitoring in the wetland must be limited to a small number of toxic substances. This can prove to be the most efficient when toxic substances are few in number and clearly identified. In other circumstances chemical measurement of toxic substances is performed only when toxic symptoms appear as the result of biological monitoring.

Direct measurement of toxic substances in the wetlands is a complicated issue and poses various problems:

- Where to measure in the ecosystem? The toxic substances can be in the water or bound to the sediment, in plant or animal tissues. The toxic substances can be recycled within the ecosystem or transferred into adjacent ecosystems (wetlands can be sinks for toxic substances).
- The concentrations can be very low (below  $10^{-6}$  g/l) thus requiring very sophisticated sampling and analytical procedures.
- Sampling frequency should be determined according to the fluxes of toxic substances. Pollution can be irregular in time (pulse) and its importance can be underestimated by infrequent sampling. This problem is more acute for very toxic chemicals which degrade rapidly (many pesticides).
- The sources of pollutants are not always obvious and the level of pollution can be underestimated because the main source is not measured. Significant amounts of toxic substances can be transported over long distances by the wind (e.g. cadmium) in wetlands where, often, only water pollution is considered.

These difficulties make it impossible for a wetland manager to establish a monitoring programme for non-biotic pollutants without a considerable level of technical and financial support; an important exception being for lead pollution resulting from hunting (see box 4.4). The selection of variables and techniques to be involved should be made according to the toxic substance most likely to occur in the wetland.

#### BOX 4.4 Monitoring lead poisoning

This type of pollution poisons ducks which ingest hunters' lead shot instead of grit with the purpose of mechanical breakdown of their food. The density of lead shot can be very high in some Mediterranean wetlands where hunting pressure is high (e.g. Camargue, Ebro delta, etc.) resulting in high frequency of lead occurrence in the gizzard of waterbirds (differing between species according to the main food and the grit size) therefore increasing the risk of poisoning.

The particularity of this pollution is that lead shot can easily be counted in the sediment and in the gizzard of birds (e.g. Pain 1992), while in most cases metal pollution is difficult to measure.

Monitoring this pollution can be achieved through direct measurements on samples of sediment in the 0–4 cm depth range exploited by birds. In parallel, lead shot can be counted in the gizzard of waterbirds harvested by hunters.



## Bio-monitoring

As for direct chemical measurements, the same difficulties make it impossible for a wetland manager to establish a monitoring programme for the precise assessment of pollution by toxic substances without significant technical, and to a lesser extent financial, support. A number of factors affect the reliability of the bio-indicators, including the variability of the rates of uptake and loss of contaminants, the age, size, sex and physiological condition of the indicator, interferences between substances and the impact of other environmental variables (e.g. temperature, salinity, organic content of water). It is not possible here to provide precise guidelines for the establishment of a monitoring programme according to the diversity of situations. Each situation must be considered in its context. However some general evaluation of the value of bio-indicators can be made for the most important toxic substances.

**Macrophytes** (bryophytes and rooted macrophytes) can be valuable indicators of metal pollution (McLean & Jones 1975, Empain 1976, Say *et al.* 1981). **Rooted macrophytes** and **bryophytes** can be valuable indicators for some metallic ions (cadmium, chromium, zinc, lead). Algae are not good indicators of pollution by pesticides or heavy metals (except copper). **Emergent and terrestrial plants** can be valuable indicators of polychlorinated biphenyls (PCBs) and polycyclic aromatic hydrocarbons (PAHs) (Jones *et al.* 1992).

**Macro-invertebrates** have been extensively used in assessing pollution of water including metals, herbicides, organochlorine and organophosphorus insecticides, and PCBs (reviewed in e.g. Hellawell 1986). Only a few groups of invertebrates have been used in bio-monitoring, but include the extensive use of **oysters** and **mussels** for coastal areas (Goldberg 1975); in France, 110 coastal sites are monitored (Claisse 1989).

**Fish** have been used extensively in toxicity tests for the complete range of toxic substances (metals, pesticides, PCBs, etc.) (reviewed in Hellawell 1986). They can also be used as accumulative bio-indicators (Philips 1977, 1978) but this is more to be considered as a research area than routine measurement. Their value for field monitoring is limited by their mobility (in order to escape the toxic stress or for migration).

**Birds and their eggs** have been widely used for the analysis of residues of organochlorine insecticides (Ormerod & Tyler 1993). Birds can be valuable indicators of pollution by heavy metals (whole body or feathers), organochlorines, aromatic hydrocarbons, organophosphates and carbamates, through physiological measurements (reviewed in Peakall & Boyd 1987, Kushlan 1993a, 1993b). However, a number of factors affect the reliability of the indicators including the rates of excretion of the toxic substance. Furthermore, a serious limitation of birds as bio-indicators is their high mobility.

### 4.3.5 Changes due to exploitation of wetland products

Mediterranean wetlands are subjected to direct exploitation and/or major tourist pressure. This exploitation is considered as unsustainable when it is carried out in such a manner that it directly or indirectly affects the continued survival of the population(s) being exploited and thus the exploitation itself. A direct threat is the over-exploitation of the resource, e.g. the capture of all the breeding stock of a fish, or over-grazing. An indirect threat could be a change in the environment brought about by the activity, e.g. the eutrophication that may result from intensive aquaculture can lead to massive fish kills or shellfish mortality caused by lack of oxygen.

The main methods of exploiting the biological production of Mediterranean wetlands are fishing (including aquaculture), livestock rearing, hunting and tourism. These can either be extensive (harvesting the production without modifying the environment in order to increase productivity) or intensive activities. The two pose different problems for wetland management.

#### 4.3.5.1 Fishing and aquaculture

Fishing is carried out especially in lakes, lagoons and estuaries, by both amateurs and professionals. The prey can be migratory or sedentary fish, or shellfish. In contrast to aquaculture, fishing exploits natural populations in their environment. Aquaculture is the intensive production of fish or shellfish reared in cages, on supports or on wetland margins. Aquaculture installations are often located in coastal lagoons or inshore coastal



waters. When the production is intensive it requires inputs of foodstuffs which contribute to the accumulation of organic waste and increase the risk of eutrophication.

Monitoring fishing and aquaculture activities on a site can be carried out at three levels: in terms of the socio-economic activity itself and of the equipment used; in terms of the prey population (fish, shellfish, crustacea); or in terms of the impact on the environment.

### Monitoring the activity

Fishing activity can be monitored by measuring the fishing effort, by recording the activities of the fishermen and the gear used, and from catch statistics.

**The number of fishermen** (professionals or amateurs) can be obtained from fishery authorities, but gives little information on the size of the catch. A decline or increase in fishing activity can result from changes in the prey populations (not solely, of course). The number of fishermen should be divided into major categories (from boats, or from the shore, using fixed gear, at connections with the sea, at aquaculture or shellfish rearing installations, etc.).

Other indicators are important for measuring fishing intensity:

- **The number of items of fishing gear** or fishing installations, their total number and number per fisherman. In the case of traps which entirely close the entrance and exit to a lagoon, the number of installations is obviously not of importance, as there is only one.
- **The number of fixed fishing installations** and the number of items of gear at each.
- **The total length of nets** with their type (gill nets, etc.) and mesh size.
- **The fishing calendar** (number of days, close season).

The indicators for aquaculture (in addition to the **number of personnel**) are:

- The **number of cages** or supports and their characteristics (size, etc.).

- The **surface area of shellfish farming**.
- The **operating timetable**.

### Monitoring the prey population (fish, crustacea, shellfish)

Monitoring the prey population must be conducted in very different ways depending on whether an extensive activity (fishing) or an intensive one (aquaculture) is being studied.

In the case of extensive exploitation of resources, monitoring can be carried out by analysing fishery statistics or by conducting *ad hoc* fishing campaigns. Care must be taken in interpreting the results which must take into account the life cycle and movements of the fish species, particularly in open systems (in lagoons as compared to lakes, which are more or less closed systems). Most commercial species in lagoons are migratory, such that the populations in any given site depend not only on local management, but also on the state of regional stocks. For example, a decrease in the eel catch in a lagoon must not always be interpreted as the result of poor local management, but must be looked at in the light of a general decline of this species in Europe and in the Mediterranean region. Long-term monitoring must be envisaged, using a baseline which integrates cyclical fluctuations.

**Fishery statistics** provide an easy source of quantitative information on fish sales. However, such statistics do not always exist and are in many cases a biased indicator: the recorded catches are usually an underestimate of total catches because of the diversity of sales outlets, and because unsold catches are not included (trash fish, damaged fish or fish unsold because of market forces). The degree of underestimation is very difficult to assess and does not necessarily remain constant with time. Locally, illegal fishing (using prohibited gear, during the close season or capture of fry, elvers, etc.) can also significantly contribute to the underestimation of catches by fishery statistics.

**Catch per species:** this value usually only relates to commercial species if monitoring is conducted on the basis of fishery statistics from cooperatives. The data can be accumulated to calculate **production**, and/or can be divided by the number of fishermen or items of fishing gear to calculate the **CPUE** (catch per unit effort), or else can be divided by the area of the wetland to obtain the **yield** (kg/ha). These data



can then be used to analyse population trends in a given site or to compare production with other wetlands.

**Population structure:** measurements of fish length or shellfish length in the catch can be used to assess the impact on the target population(s) over time. The extent of **imbalance in size classes** (related to fishing practices and regulations) gives an indication of the state of the populations and provides a measure of reproductive success (abundance of fish of breeding age and recruitment).

**Direct measurement of the population or community structure** provides information that does not have the same bias as fishery statistics. Monitoring can be restricted to endangered species or those with a particular interest, or can cover the whole fish community to obtain comprehensive information for a lagoon or lake. Such data, collected by fishing campaigns designed with this aim in view, can also be used to determine the fate of introduced fish species (often deliberately introduced for economic reasons).

A whole range of different sorts of fishing gear must be used to capture the various species and size classes (see Arrignon 1970, Lam Hoai & Lasserre

1984). Each type of gear catches species and/or size classes with very different degrees of efficiency, depending on the characteristics of the fish and the gear. Such fishing campaigns provide good information on introduced and/or non-commercial species. They can reveal imbalances in the community (e.g. ratios of herbivores to predators, or benthic to pelagic species), which in turn can affect the communities of plants and benthic or planktonic invertebrates, and can also detect changes related to exchanges with the sea (e.g. ratio of sedentary to migratory species). The main inconvenience of this method is that it is costly and time-consuming to make repeated fishing campaigns. The greatest care must be taken in preparing a sampling plan so as to guarantee the greatest standardisation in measurements and decrease the variance, which is usually very high.

### Impact on the environment

Fishing has impacts that are not just restricted to fish or shellfish catches in the site. It has a deleterious effect on aquatic bird populations because of the disturbance and accidental mortality it causes. Fish-eating birds are trapped by fishing gear, disturbed by the passage of boats and are shot or have their nests destroyed by fishermen. It is

**Plate 4.3** Wetlands are often converted into aquaculture: fish farms in the valley of the Mira river, in southern Portugal. (João Carlos Farinha)





difficult to measure these impacts, since they vary greatly depending on local conditions and practices.

**Counts of birds, counts of birds caught in nets, observation of bird behaviour** at the approach of a boat and **breeding success** can be used as indicators of the impact of fishing on bird populations.

Intensive fish or shellfish aquaculture in a wetland can affect the indigenous communities and the entire ecosystem. The impact on the indigenous community can result from the introduction of parasites or diseases and/or from the capture of fry or spawn from the natural environment for fattening in aquaculture installations.

Aquaculture can also have considerable impacts on the entire ecosystem. Intensive cage rearing leads to major organic pollution caused by the inputs of foodstuffs, part of which is unconsumed, and especially by the excretion of organic matter by the animals. This pollution can expose the site to the risk of eutrophication, which can threaten entire plant and animal communities and even the aquaculture exploitation itself, by episodes of anoxia. Appropriate indicators are those of eutrophication, in particular **physico-chemical indicators for the water and sediment** and also **biological indicators** (e.g. **development of macro-algae**). See above section on eutrophication.

#### 4.3.5.2 Grazing

Wetlands are often intensively grazed by domestic cattle, horses and sheep. The impact of the animals varies depending on the pressure exerted, the species and breed used and the plant communities and their position in the succession (Gordon *et al.* 1990). Wild herbivores (rabbits *Oryctolagus cuniculus*, coypu *Myocastor coypus*, wild boar *Sus scrofa*, etc.) can also have a considerable impact on wetlands.

Livestock have a major impact on habitat structure through direct impact on the vegetation and they also have an impact on plant production (e.g. Crawley 1983, Bakker 1985). Two aspects of the impact of livestock must be taken into account. Firstly, grazing is a management tool which can produce vegetation structures compatible with management aims; but, on the other hand, grazing is an activity that has an impact of varying severity on all parts of the ecosystem, so it may not necessarily be compatible with management aims. These two aspects are obviously closely linked, but the activity is controlled by two distinct factors with different aims, frequently working to different time scales: the livestock farmer is interested in more or less short-term profitability and the maintenance of the pastoral value; whereas the aims

Plate 4.4 The impact of grazing on the structure of the vegetation can be monitored using exclosures. (Pere Tomàs Vives)





of the wetland manager are related to the long-term conservation of the natural heritage. Moreover, wetland managers are only interested in the animals when they are present on the site, which may be brief, whereas the farmer has to take account of the whole annual cycle, which includes critical periods such as calving, foaling and lambing, and wintering.

The sustainability of grazing activity does not mean the same thing to the wetland manager and the farmer. Managers think of sustainability in terms of their aims (plant populations, habitat structure, income from rent), whereas farmers think of it from the viewpoint of economic viability, which depends on the duration and conditions of grazing rights.

Two groups of indicators can be used to monitor grazing: indicators of grazing pressure (the stock density) and indicators of the impact of grazing.

### Monitoring grazing pressure

The first indicators of grazing pressure are the **numbers of animals present** on the site, distinguishing the various species of domestic livestock and their classes (yearlings, sub-adults, non-lactating females, lactating females and males), and at different spatial scales. Grazing pressure can be expressed in animal-days and the **grazing calendar** must be defined (pressure calculated per month or per season).

Further additional indicators are useful for assessing the stock density in relation to the carrying capacity of the land. These include the **quantities of any supplementary fodder** provided by the farmer(s). Such supplements indicate clearly that the number of animals is too great in relation to the forage present, and this is often accompanied in wetlands by severe poaching of soils, by trampling.

**Spatial distribution** of grazers is also an important factor because in natural areas animals will select their feeding areas among a mixture of vegetation units (Duncan 1992). The resulting grazing pressure may be very high on the preferred landscape units (e.g. dry grassland versus flooded marshes) and/or on those more sensitive to trampling or grazing (e.g. dunes, soils rich in organic matter).

The number of wild animals can also be measured or estimated using a semi-quantitative index (e.g.

**number of animals seen along a line transect**). This is obviously much less precise than for domestic livestock. Protocols for **counting along fixed transects** can provide indices of abundance (e.g. distance sampling). **Counts of dropping density** (or **dropping accumulations**) within quadrats or along transects can provide an index of animal density.

### Monitoring the impact of grazing

Two criteria can be used for selecting indicators of grazing impact, depending on the aims of grazing:

1. the management of grazing itself, which can effect the long-term survival of the resource by changing its structure and production and also the pastoral value of the vegetation.
2. the effectiveness of grazing as a tool for attaining precise management objectives.

The indicators of the impact of grazing on the vegetation will be selected from among the standard indicators of grazing activity. **Production** can be evaluated from measurements of the vegetation structure (**species composition, height, total cover**). When the grazing pressure is greater than the rangeland carrying capacity, the quality and production of the pastures decrease as a result of:

- an increase in the area of bare soil, which is a symptom of a decline in the initial standing crop of plants from which production takes place.
- the replacement of good forage species by less palatable or rejected ones.

The value of a pasture can be assessed from these indicators (Crawley 1983) which include the **percentage of bare ground**, the **abundance of rejected plants** and **scrub encroachment**, and the **abundance of the best forage species**. Other indicators, such as the **ratio of abundance of annuals/perennials** and the **ratio of abundance of Leguminosae/Dicotyledons**, can be added. It should be noted that all these indicators require the presence of a valid control plot, since they are also affected by other factors. Trampling by domestic herbivores can have a drastic impact on vegetation and soils. Trampling can be measured by the **compaction of soils** or by other indicators which are



also related to grazing: *species composition* of vegetation, *relative abundance of resistant growth form* (e.g. rosettes), *percentage of bare ground*.

The success of the use of grazing as a management tool is assessed from criteria which are specific to the management objectives. This therefore involves the relative assessment of the management objectives, and the indicators must be related to these objectives. The selection of indicators is helped by an analysis of the impact of grazing on the vegetation structure or the structure of the habitat for the target species. It is wise to choose an indicator which is close to the action of grazing, even if the aim of management is an animal. The action of grazing can change or maintain a structure favourable to an animal species (e.g. birds), but change in the abundance of that species is not a good indicator of the success of management as its abundance can vary greatly as a result of external factors unrelated to the vegetation or habitat structure.

From an ecological viewpoint, the aims of wetland managers are often to maintain ecosystems at a young stage of plant succession and to reduce the cover and abundance of vigorously growing dominant species (trees, reeds, etc.). These aims require a high grazing pressure. The indicators must be chosen in terms of precise management objectives; these will often be the *cover of each vegetation stratum* (herbs, shrubs, trees), or the *diversity* or *species richness*, or the *abundance of a particular target species* (cover or number of individuals, depending on the case). These indicators are also influenced by other environmental and particularly climatic factors and also by the flooding regime, so the monitoring protocol must include a reference area to take these into account.

#### 4.3.5.3 Hunting

Hunting of waterbirds is an important activity in Mediterranean wetlands, which exploits a proportion of the natural populations. Hunting has both direct and indirect impacts on the populations of game and non-game species as a result of shooting, disturbance, lead poisoning and from management conducted for hunting purposes. The sustainability of hunting activities can be assessed at two levels: that of the total populations and that of the site. Hunting activity can be monitored by the *numbers of licences*, the

*number of hunters per day*, the *length of the hunting season*, the *number of days* when hunting is allowed and the *number of shots per unit time* (Landry 1990).

#### Direct impact on waterfowl populations

Hunted waterbird species often have large populations which are spread over many sites; the majority of hunted species are also highly migratory. Each site supports a small proportion of the total population and impacts there alone are unlikely to affect the whole population. National and international hunting regulations, if they are obeyed, allow hunting to be practised sustainably. Moreover, monitoring of wintering waterfowl populations around the Mediterranean is carried out by an extensive network of observers (*International Waterfowl Census* coordinated by Wetlands International, formerly IWRB) which is capable of detecting major changes in populations (see Rose 1995, Rose & Scott 1994).

The direct impact of hunting is important at the level of the site itself. Heavy hunting pressure leads to a decrease in the number of birds. The monitoring of the *number of individuals* of each species is the best indicator of excessive hunting. Nevertheless, hunting is not the only factor affecting the populations of game species, so the trends recorded locally must be compared with more general trends or those recorded on a control site free from hunting. The *kill statistics* measure the pressure that hunting activity exerts on populations. However the *trends over time of the total number of animals or by hunterday* can be an indicator of the sustainability of hunting.

#### The indirect impact

The indirect impact of hunting manifests itself mainly at local level through the disturbance of game and non-game species, through lead poisoning (see box 4.4) and by management activities that modify habitats. During the non-breeding season waterbirds need to meet at least two basic requirements, feeding and roosting. Hunting activity becomes unsustainable at a site when it interferes severely with one or other of these requirements. The disturbance caused by hunting can be assessed by *counting game and non-game species* on sites with hunting, provided



there is a valid control (one or more sites free from hunting, or the level of regional populations, etc.). The effects of shooting disturbance are reviewed by Bell & Owen (1990).

Management aimed at increasing the hunting bag is a major factor causing modification of wetlands, particularly in the south of France. The flooding regime of wetlands is greatly influenced by the dates of the start and end of the hunting season, and is far from natural (Tamisier & Grillas 1994); this in turn affects the animal and plant populations. Waterfowl hunting also favours extensive areas of open water to the detriment of more closed habitats such as reed beds. In this case the most pertinent monitoring is not that of the hunting itself, but the overall monitoring of the wetland **flooding regime** and of the **habitat and vegetation structure** (see above).

#### 4.3.5.4 Tourism and recreation

Tourism and recreation lead to various types of disruption which may endanger the biological diversity of Mediterranean wetlands. The main types of disruption caused by tourism are wetland destruction (for construction of tourist facilities), pollution, visitor disturbance and trampling.

Monitoring of the first two points is dealt with elsewhere in this chapter (see sections on changes in wetland area and on eutrophication).

Tourist pressure is a source of disturbance for the fauna, whose consequences vary greatly depending on the species in question and the visitor facilities. The most important indicator of visitor pressure is obviously the **number of visitors** (per day, month, year, etc.) and the human activity (i.e. the **type of disturbance**: fisherman, boats, windsurfers, etc., Tuite *et al.* 1984, Ahlund & Gotmark 1989, Kahlert 1994). Nevertheless, the disturbance caused by visitors can be minimised if adequate provisions are made (Goldsmith 1983). As a result, the number of visitors on its own is not a good indicator of the degree of disturbance if several sites are considered. An indicator of the degree and intensity of disturbance must be added to the number of visitors (**numbers per type of activity**). Several indicators can be used to assess the disturbance caused by tourism. Among these are the **numbers of individuals** of each species (birds mainly), comparing between sites, or between days with and without visitors, or at different times of day. Analysis of the **behaviour of animals** can also provide a measure of the intensity of disturbance: e.g. departures, time spent in vigilance, nest desertion, etc. (Kahlert 1994), and of the tolerance

Plate 4.5 Tourism is a cause of disturbance in sensitive areas. Lagoa de Albufeira, Portugal. (Pere Tomàs Vives)





of the species to disturbance (Keller 1991, Kahlert 1994). The **rate of predation** on nests can be increased as a result of disturbance (Ahlund & Gotmark 1989).

Trampling by people, horse riding or vehicles can be a further consequence of excessive visitor pressure on sites. Coastal wetlands with unstable substrates (dunes) are particularly sensitive to trampling. The classical consequences in terms of vegetation structure are an increase in the **cover of bare soil** and/or a change in **species composition**. Species sensitive to trampling are replaced by other more tolerant plants (e.g. annual, creeping or rosette species of small size).

The spraying of chemicals for mosquito control is also an important indirect effect of tourism and recreation.

#### 4.3.6 Changes due to the introduction of alien species

The functioning of Mediterranean wetlands is increasingly being affected by species of alien plants (higher plants and algae) and animals (invertebrates, fish, mammals, birds, etc. – see chapter 2). The introduced species disturb ecosystems in different ways: by replacing indigenous species, by genetic pollution, by the introduction of pathogens or by modifying habitat structure. It is however often difficult, under field conditions, to establish cause and effect relations between the introduction of alien species and the decline in indigenous species (Taylor *et al.* 1984, Rosecchi *et al.* 1993).

Monitoring alien species already introduced in wetlands can be carried out by using standard indicators for animal and plant population size. These indicators obviously vary depending on the species or group in question (invertebrates, birds, plants, etc.) and it would be inappropriate here to give a detailed list of possible indicators.

Monitoring alien species that have just arrived at a site is more difficult to organise. The diversity of species and groups would make it very costly and ineffective to conduct an exhaustive monitoring programme. New species are likely to be identified through other monitoring schemes or field surveys, particularly for species which are disseminated by water (especially floating plants). When a species has a high probability of invading a site (e.g. when

present nearby) a specific, but non-intensive, monitoring programme could be envisaged using methods appropriate for the species.

## 4.4 Conclusion

The selection of indicators is a critical stage in planning a monitoring programme. It has to be integrated in the whole process of planning. The first immediate relationship is with the objectives of the monitoring programme and with specific hypotheses on future and current ecological change. Scale of time and space, resources, staff expertise and information available are some of the most important external factors that influence the choice among the huge variety of possible indicators.

Both physical and biological parameters can constitute valuable indicators for ecological change. Biological indicators range from the infra-cellular level to synthetic indices derived from the composition of species assemblages. There are no recipes that can help in the selection of the indicators. An ideal indicator should give a clear and unambiguous answer and give early warning for the selected hypothesis. However, no such ideal indicator exists or can be identified for all situations. The process of selection should rely upon a functional analysis of the wetland monitored. It is based on the assumption that the biological diversity and individual species will persist if the quality of habitat is maintained. The selection of the indicators should be related as much as possible to the processes involved with ecological change and address in the first instance the key environmental factors which control habitat structure and production. A number of indicators are proposed for different situations (threats/type of wetlands) but, although they are believed to apply widely, they are given as examples to illustrate the process of selection and in no way are supposed to fit all situations.

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# 5 Techniques for monitoring

*Pere Tomàs Vives and Patrick Grillas*



*This chapter is a summary of the information presented in chapter 4 on Identification of indicators for monitoring ecological change. It is intended to provide guidance in a structured and systematic format (tables) about the possible indicators and techniques that can be used to monitor the different types of ecological change. The tables also provide bibliographic references, where a discussion about the use of the different indicators or the description of the technique can be found. All the references presented in these tables are listed in chapter 6.*

*The tables are organised to conform with the types of ecological change presented in the previous chapters, i.e.*

- *changes in wetland area*
- *changes in water regime*
- *changes in water quality:*
  - *eutrophication*
  - *pollution by toxic substances*
- *changes due to exploitation of wetland resources:*
  - *fishing and aquaculture*
  - *grazing*
  - *hunting*
  - *tourism and recreation*
- *changes due to the introduction of alien species*

*As in the previous chapters, these tables are not intended as recipes but instead provide guidance for selecting the most appropriate indicators and techniques.*



TABLE 5.1 Monitoring changes in wetland area.

Group	Indicators	Techniques	References and Comments
Habitat and communities	List of Habitat types	MedWet habitat description system CORINE biotopes classification	Farinha <i>et al.</i> 1996 European Communities Commission 1991 Devillers & Devillers-Terschuren 1993
	List of plant communities	Phytosociology Others (e.g. structural classification, dominant species, etc.)	Braun-Blanquet 1932 Goldsmith <i>et al.</i> 1986 See also chapter 6
	Habitat patchiness, Fragmentation	Classifications (MedWet, CORINE, etc.) Field measurements Mapping Remote sensing GIS	Farinha <i>et al.</i> 1996; Zalidis <i>et al.</i> 1996 European Communities Commission 1991 Devillers & Devillers-Terschuren 1993 Cowardin 1979 See also: Moore & Chapman 1986; Greig-Smith 1983 Budd 1991; Mather 1993 See also chapter 6
Spatial indicators	Surface area of habitat types		
	River length		
	Trend analysis over time (reveals rates of wetland loss)	Mapping Remote Sensing GIS	Frayer <i>et al.</i> 1983a & 1983b Dahl & Johnson 1991; Dahl 1993 Environmental Protection Agency 1992 Requires (stratified) random sampling for selection of sites to monitor
Trend indicators	Comparative analysis with other regions		
	Comparative analysis with other trends		



TABLE 5.2 Monitoring changes in water regime.

Group	Indicators	Techniques	References and Comments
Level of water	Surface water Groundwater	Measurement of surface water levels Measurement of groundwater level in wells, piezometers	Easy and cheap Gilman 1994 Easy
Water balance of the wetland (balance between the inputs and the outputs of water)	Precipitation Surface inflows and outflows Groundwater inflows and outflows Evapotranspiration Tides	Precipitation: pluviometer, pluviograph Surface inflow/outflow: channel gauge (manual or automatic) channel cross section x water velocity estimation of surface runoff Groundwater inflow/outflow: estimation using Darcy's law Evapotranspiration: measurement with evaporation pans, or estimation using Penman's equation	Mitsch & Gosselink 1993 Gilman 1994; Brassington 1988 Chalmers & Parker 1985 Some of the measurements are easy and cheap to do (e.g. pluviometer), whereas others require infrastructure (e.g. channel gauge) and are more expensive (e.g. automatic recorders) Evapotranspiration and groundwater inflow/outflow are difficult to calculate
Salinity of water	Salinity (g/l) of surface and ground water	Measurement of the concentration of NaCl Salinometer	Chalmers & Parker 1985 Environmental Protection Agency 1992 Indicates water fluxes through dilution and concentration effects Groundwater salinity in piezometers, wells
	Electric conductivity	Conductivity meter	Chalmers & Parker 1985 Easy, cheap
Temperature of water	Temperature of surface and groundwater	Thermometer, thermocouple, thermistor	Environmental Protection Agency 1992 Chalmers & Parker 1985 Indicates possible input of water at different temperature (e.g. cooling water from industry, power plants)
Plants	Ratio of annual/perennial species No. terrestrial/amphibious/aquatic species Glycophyte/Halophyte species Presence of certain species	Measurement of species frequency	Indicates the intensity of the stress Only recommended when direct hydrological measurements are not possible
Invertebrates	Presence of certain species/groups (e.g. Phyllopods)	Techniques depend on the groups	In certain marshes, indicates isolation Only recommended when direct hydrological measurements are not possible
Fish	Presence of certain species	Fish sampling techniques	Lam Hoai & Lasserre 1984; Arrignon 1970; Environmental Protection Agency 1992 Indicates permanence of water over the year, or permanent connection between waterbodies



TABLE 5.3 Monitoring changes in water quality: eutrophication.

Group	Indicators	Techniques	References and Comments
Nutrients in the water	Quantities of nutrients in water entering the wetland (nutrient budget)	Concentrations of nutrients in water: specific techniques for each nutrient	Mitsch & Gosselink 1993; Allen et al. 1986 See review in Environmental Protection Agency 1992 Complex and difficult to measure Annual pattern must be established
Indicators of nutrients in the sediment	Total phosphorus and total nitrogen	Concentration of nutrients: specific techniques for each nutrient	Hellawell 1986 Environmental Protection Agency 1992 Indicates anthropogenic eutrophication Annual pattern must be established; varies with depth
	Nutrient profiles: concentrations of nutrients along depth gradients	Concentration of nutrients: specific techniques for each nutrient	Indicates eutrophication rates Annual pattern must be established
	Redox potential	Redox potential meter	Mitsch & Gosselink 1993 Indicates quantity of organic matter (OM) and processes of decomposition of the OM, and availability of oxygen; varies with water velocity, sediment particle size composition, depth
	Water transparency	Secchi disk	Margalef 1983 Environmental Protection Agency 1992 Easy, cheap, requires high frequency because it is sensitive to dynamic factors, (e.g. abundance of phytoplankton, suspended soils, etc.) Measurements vary with the observer
Indicators in the water column	Light attenuation profile	Light sensors (automatic or manual)	Chalmers & Parker 1985 Precise, more expensive, requires high frequency because it is sensitive to dynamic factors
	Oxygen concentration	Dissolved oxygen meter (usually a probe)	Related to primary production if recorded over 24 hours period, requires high frequency because it is sensitive to dynamic factors
	pH	pH meter (usually a probe)	Chalmers & Parker 1985 Related to primary production if recorded over 24 hour period or at same time of day
	Density	Inverted microscope (no. cells/ml)	Time consuming; requires high knowledge of taxonomy or use of Operational Taxonomic Units (OTU)
Microphytes (planktonic, epiphytic & benthic algae)	Biomass, production (e.g. Phytoplankton biomass is related to phosphorus)	Concentration of chlorophyll <i>a</i> and <i>b</i> (fluorometry, spectrophotometry)	See review in Hellawell 1986 Environmental Protection Agency 1992 Variable parameters; baseline difficult to establish; needs weekly sampling and large number of sampling sites
		Concentration of O <sub>2</sub>	Useful in deep waters, not in shallow waters



TABLE 5.3 ... continued Monitoring changes in water quality: eutrophication.

Group	Indicators	Techniques	References and Comments
Microphytes ... continued	Species composition	Inverted microscope (glass slides, artificial substrate)	Time consuming; requires high knowledge of taxonomy or use of OTUs
Macrophytes (Angiosperms & macro-algae)	Diversity of species or of Operational Taxonomic Units (OTU)	Diversity indices (e.g. species richness; Shannon-Weiner, Simpson, etc.)	Spellerberg 1991; Magurran 1988; Margalef 1986; Krebs 1972
	Species composition	Species sampling (quadrats, etc.)	Chalmers & Parker 1985 Macrophytes are easy to identify and have low short-term variability Their response to eutrophication is not well documented
	Diversity of species	Diversity indices (e.g. species richness; Shannon-Weiner, Simpson, etc.)	Spellerberg 1991; Magurran 1988; Margalef 1986; Krebs 1972 Difficult to separate the effects of different stresses
	Biomass or frequency of different groups: Angiosperms, Rhodophyceae, Chlorophyceae	Species abundance	<i>Enteromorpha</i> , <i>Ulva</i> indicate high levels of nitrates <i>Ruppia</i> , <i>Polymogeton</i> are tolerant to eutrophication, at low salinity Useful in lagoons
	Cover of floating macro-algae	Presence and cover of floating macro-algae	Indicates advanced stages of eutrophication in lakes, rivers, lagoons and shallow bays
Macro-invertebrates	Maximum depth colonisation of submerged rooted macrophytes	Measurement of maximum depth colonisation	Related to light attenuation Indicates light budget at bottom of lakes, lagoons during the growing season Also depends on other factors: suspended solids, salinity, water depth, etc.
	Species composition, abundance	Nets Kick sampling Artificial substrates Sediment sieving	Chalmers & Parker 1985 Gray & Pearson 1982 Useful in rivers, lakes, lagoons and sea Due to high variability in space and time requires high number of samples, and time consuming analysis Requires high knowledge of taxonomy or use of OTUs
	Ratio of different groups (or species)		
Vertebrates (fish)	Species composition of fish communities	Fish sampling techniques	Lam Hoi & Lasserre 1984; Arrignon 1970; Environmental Protection Agency 1992 Can be indicators of the trophic levels of lakes



TABLE 5.4 Monitoring changes in water quality: pollution by toxic substances.

Group	Indicators	Techniques	References and Comments
Levels of toxic substances (detergents, organohalogenes and organophosphorus pesticides, heavy metals, hydrocarbons, etc.)	Concentration of toxic substances	Direct measurement of concentration of toxic substances using techniques specific to the different toxic substances  Toxicity tests	Hellawell 1986; Allen <i>et al.</i> 1986 See review of methods in Environmental Protection Agency 1992 See review of toxicity tests in Spellerberg 1991 FAC 1989; Gupta <i>et al.</i> 1989; Merian 1984 Need to determine the most likely toxic substances in the wetland before deciding which test Expensive, sophisticated equipment needed. sampling frequency difficult to determine
	Radionuclides	Geiger counter or specific techniques depending on radionuclides	Expensive and equipment not readily available Only relevant in limited areas
	Macro-invertebrates	Measure concentration of toxic substances in tissues using techniques specific for the different substances	Environmental Protection Agency 1992 Goldberg 1975; Goldberg <i>et al.</i> 1978 Some bivalves (e.g. oysters, mussels) are used for monitoring bio-accumulation of PAHs, PCBs
	Fish	Measure concentration of toxic substances in tissues using techniques specific for the different substances	See review in Hellawell 1986 Environmental Protection Agency 1992 Fish are used for a wide range of toxic substances: metals, pesticides, PCBs
	Birds	Measure concentration of toxic substances in eggs, body, feathers, etc. The techniques are specific for the different substances	Peakall & Boyd 1987; Ormerod & Tyler 1993a, 1993b Bird eggs used for organochlorine insecticides, and whole body or feathers for heavy metals, organochlorines, aromatic hydrocarbons, organophosphates and carbamates Problem of using birds due to their high mobility
	Lead poisoning (ingestion of lead shot by birds)	Density of lead shot in the sediment Manual examination of gizzard contents (no. of lead shot) Fluoroscopy X-ray (live or dead birds, gizzard, or gizzard contents) Atomic absorption spectrometry (body tissues: liver, kidney, pancreas, bone)	Pain 1989, 1991; Montalbano & Hines 1978; Guitart <i>et al.</i> 1994 Manual gizzard analysis misses 24–42% of shot present Blood, liver & kidney concentrations indicate recent exposure to lead
Bio-monitoring	Macrophytes	Species presence or assemblage	Empain 1976; McLean & Jones 1975 Bryophytes & rooted macrophytes can indicate metal ions (Cd, Cr, Zn, Pb) Algae are useful for Cu Emergent and terrestrial plants can indicate PCBs and PAHs
	Macro-invertebrates	Species presence or assemblage	See review in Hellawell 1986 Used as indicators of metals, herbicides, organochlorine & organophosphorus insecticides, PCBs



TABLE 5.4 ... continued Monitoring changes in water quality: pollution by toxic substances.

Group	Indicators	Techniques	References and Comments
Bio-monitoring ... continued	Fish	Observation of fish behaviour Detection of fish pathologies	See review in Hellawell 1986; Spellerberg 1991 Environmental Protection Agency 1992 Fish are used for a wide range of toxic substances: metals, pesticides, PCBs Problem of using fish due to their mobility
Biotic indices	Biotic indices	Different indices can be used depending on the situation	See review in Spellerberg 1991; Hellawell 1986 Environmental Protection Agency 1992 Difficult to separate the effects of different stresses Do not provide early warning



TABLE 5.5a Monitoring changes due to fishing and aquaculture.

Group	Indicators	Techniques	References and Comments
Monitoring the activity	Fishing: no. fishermen (classified according to type of fishing), no. items of fishing gear and type, no. fixed fishing installations, total length of nets, fishing calendar	Certain types of data (e.g. no. professional and amateur fishing licences; fishing calendar, etc.) can be obtained from the fisheries authorities; others have to be measured on site (at regular intervals)	These parameters indicate the intensity of the activity but not its effect on the populations and the habitats
	Aquaculture: no. of personnel, no. of cages and type, surface area of shellfish farming, operating timetable	These data could be obtained from the exploiting person/company or from the fisheries authority	
	Catches per species from fishery statistics	Data can be obtained from fisheries authorities, fishermen cooperatives, etc.	
	Production CPUE (catch per unit effort) Yield	Direct measurement and calculation	
Monitoring prey population	Population structure (measurement of fish/shellfish length)	Existing data can be obtained from marine research institutes, universities, fisheries authorities, etc.	Easy quantitative information on fish sales Recorded catches are normally an underestimate of total catches (side market sales, unsold catches, illegal fishing, etc. are normally not included) Only covers commercial species  Lam Hoai & Lasserre 1984; Arrignon 1970; Potts & Reay 1987; Environmental Protection Agency 1992 Data can be used to analyse population trends in a site or compare with other sites
	Population size Community structure	Direct measurement Fishing campaigns using nets, traps, etc.	
	Birds caught in fishing gear	Counts of birds caught in nets, traps, etc.	
	Disturbance caused by passage of fishing boats: no. individuals of species susceptible to disturbance; modifications of animal behaviour (departures, nest desertion, etc.) Destruction of nests	Counts of birds Animal behaviour study techniques Measurement of the breeding success	
Monitoring the impact	Aquaculture: effects on indigenous species, communities, etc.	Detection of introduced parasites, diseases, etc.	Adequate for endangered or interesting species; and to determine the fate of introduced species Expensive, time consuming (See same references as above)  Bibby <i>et al.</i> 1992  Late warning indicators
	Aquaculture: indicators of eutrophication	See table 5.3 (eutrophication)	
	Aquaculture: area of wetland lost or changed; habitat fragmentation	See table 5.1 (changes in wetland area)	
		See table 5.3 (eutrophication) See table 5.1 (changes in wetland area)	



TABLE 5.5b Monitoring changes due to grazing pressure.

Group	Indicators	Techniques	References and Comments
Monitoring grazing pressure	No. heads/day (per sex and age classes) in a determined area, grazing calendar	Certain types of data can be obtained from the agriculture authorities, others have to be measured on site (e.g. by counts)	These parameters indicate the intensity of the activity but not its effect on the populations and the habitats
	Additional food supply	Record additional amounts of fodder supplied	Useful to assess stock density in relation to carrying capacity
	Spatial distribution of grazers	Counts, vegetation studies	Duncan 1992
	Condition of the animals	Measurement of body weight, height, etc.	Duncan 1992; Evans 1977
	Wild species: indirect parameters, e.g. semi-quantitative indices of abundance	Distance sampling, e.g. counts along fixed transects, counts of dropping density	Provide an indirect estimate of wild herbivore populations
Monitoring the impact of grazing	Production, species composition, height, total cover, etc.	Different techniques depending on the parameter(s) selected(s): mapping, vegetation study techniques, e.g. exclosures, quadrats, transects, fixed point photographs, etc.	Duncan 1992 Bhadresa 1986 Goldsmith <i>et al.</i> 1986 Crawley 1983
	Percentage of bare ground		
	Abundance of best forage species		
	Abundance of rejected species (e.g. bushes, ungazied species, etc.)		
	Scrub encroachment		
	Ratio of annual/perennial species		
	Ratio Leguminosae/Dicotyledons		
	Compaction of soil, relative abundance of resistant growth forms (e.g. rosettes), species composition, percentage of bare ground		A valid control plot is needed, since these indicators can be affected by other factors
	Condition of the animals	Measurement of body weight, height, etc.	Indicate the effect of trampling by herbivores
			Duncan 1992; Evans 1977
Monitoring of grazing as a management tool	Species composition	Different techniques depending on the parameter(s) selected: mapping, vegetation study techniques, e.g. exclosures, quadrats, transects, fixed point photographs, etc.	Vegetation study techniques: Duncan 1992; Bhadresa 1986; Goldsmith <i>et al.</i> 1986; Crawley 1983
	Productivity/Biomass		Diversity indices: Spellerberg 1991; Magurran 1988; Margalef 1986; Krebs 1972
	Objective: stop vegetation succession Indicator: cover of each vegetation stratum (e.g. herbs, shrubs, trees)		Bird census techniques: Bibby <i>et al.</i> 1992 Amphibian study techniques: Heyer <i>et al.</i> 1994
	Objective: increase area of open water Indicator: surface area of open waters *	Mapping techniques (see table 5.1 changes in wetland area)	The indicators are specific to the objectives of management Assessment of the impact of grazing on vegetation structures recommended
	Objective: increase diversity Indicator: diversity of species	Diversity indices (e.g. species richness; Shannon-Weiner, Simpson, etc.)	It is also recommended to choose indicators that are close to the action of grazing A valid control plot is needed, since these indicators can be affected by other factors
	Objective: increase target species nos. Indicator: abundance of target species	Measure the abundance (census, etc.) of individuals of target species	

**TABLE 5.5c Monitoring changes due to hunting.**

Group	Indicators	Techniques	References and Comments
Monitoring hunting pressure	No. hunting licences (classified according to type of hunting), hunting calendar; no. hunting days No. hunters/day in a site No. shots/hour	Certain types of data (e.g. no. hunting licences; hunting calendar, etc.) can be obtained from the hunting authorities; others (e.g. no. hunters/day) have to be measured on site (at regular intervals)	These parameters indicate the intensity of the activity but not its effect on the populations and the habitats
Direct impact on waterfowl populations	No. individuals present of game and non-game species  Trends in waterfowl populations Bag size (no. birds shot/day)	Periodic bird census during the hunting season National or local waterfowl trend studies  International Waterfowl Census  These data can sometimes be obtained from hunting associations	Bibby <i>et al.</i> 1992 Data recorded locally must be compared with more general trends, or with trends at control sites (free of hunting)  Rose 1990, 1995; Rose & Scott 1994
Indirect impact: disturbance of species	No. individuals present of game and non-game species  Bird body condition and rate of fat accumulation Time spent feeding	Periodic bird census  Study of birds' abdominal profile Bird observations	Bibby <i>et al.</i> 1992; Bell & Owen 1990 Data recorded locally must be compared with more general trends, or with trends at control sites (free of hunting)  Madsen 1994 Smit & Vasser 1993
Indirect impact: modification of habitats due to management for hunting	Lead poisoning Flooding regime Vegetation structure Habitat fragmentation	See table 5.4 (pollution by toxic substances) Dates of flooding/drying, water levels, etc. See table 5.2 (changes in water regime) Mapping: vegetation study techniques (see tables 5.1 and 5.5b) See table 5.1 (changes in wetland area)	See table 5.4 (pollution by toxic substances) See table 5.2 (changes in water regime) See tables 5.1 and 5.5b See table 5.1 (changes in wetland area)



TABLE 5.5d Monitoring changes due to tourism and recreation.

Group	Indicators	Techniques	References and Comments
Changes in wetland area	Area of wetland lost or changed Habitat fragmentation	See table 5.1 (changes in wetland area)	See table 5.1 (changes in wetland area)
Pollution	Concentration of nutrients Faecal pollution Spray of toxic substances for pest control (e.g. mosquito)	See table 5.3 (eutrophication) Measurement of levels of faecal bacteria Techniques depending on type of product	See table 5.3 (eutrophication)  See table 5.4 (pollution by toxic substances)
Tourist pressure	No. visitors (per day, month, year) Distribution of visitors Type of activity done by visitors	Counts of visitors or vehicles at fixed point (e.g. entrance to site), along transects, per unit of time Time-lapse photography Visitor questionnaire surveys	Goldsmith 1983; Goldsmith <i>et al.</i> 1970 These parameters indicate the intensity of the activity but not its effect on the populations and the habitats
Trampling	Percentage of bare ground Species composition, presence of plants tolerant to trampling (e.g. annual, creeping, rosette species) Vegetation structure	Different techniques depending on the parameter(s) selected(s): mapping; species abundance; vegetation study techniques, e.g. quadrats, transects, fixed point photographs, etc.	See tables 5.1 and 5.5b Indicate degree of trampling due to visitor pressure
Disturbance	No. individuals of species susceptible to disturbance	Census of animal species	Bibby <i>et al.</i> 1992 Data recorded locally must be compared with more general data, or with control data (e.g. counts in days/times without visitors) Allows comparison between sites
	Modifications of animal behaviour (departures, nest desertion, etc.) Destruction of nests; rate of predation	Animal behaviour study techniques Measurement of the breeding success and of the rate of predation	Late warning indicators



TABLE 5.6 Monitoring changes due to introduction of alien species.

Group	Indicators	Techniques	References and Comments
Population size	The indicators and the techniques depend on the group to which the introduced species belongs (plants, invertebrates, fish, amphibian, reptiles, birds, mammals)	Vegetation study techniques Animal study techniques	Moore & Chapman 1986 Southwood 1978; Pollard & Yates 1993 Lam Hoai & Lasserre 1984; Potts & Reay 1987 Heyer <i>et al.</i> 1994; Bibby <i>et al.</i> 1992 Davies 1982
Effects on native species	Inter-specific breeding	The techniques depend on the group Census of hybrid individuals (e.g. <i>Oxyura jamaicensis</i> ).	See above
	Predation Competition	The techniques depend on the group: vegetation sampling techniques, census of native prey or competitor species, etc.	See above
Effects on the hydrology	Level of water table	Measurement of level in piezometers, wells (e.g. changes due to <i>Eucalyptus</i> plantations) See table 5.2 (changes in water regime)	See table 5.2 (changes in water regime)
	Water regime	See table 5.2 (changes in water regime)	See table 5.2 (changes in water regime)
Effects on habitat structure	Vegetation structure	Vegetation study techniques See tables 5.1 and 5.5b	See tables 5.1 and 5.5b