Wetland monitoring

a practitioner's guide

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Written by Wildfowl & Wetlands Trust

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Monitoring at Orog Lake, Mongolia (photo by Gombobaatar Sundev)

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Ramsar Convention: The Convention on Wetlands of International Importance, also known as the Ramsar Convention, is an intergovernmental treaty that provides the framework for national action and international cooperation for the conservation and wise use of wetlands and their resources as a contribution towards sustainable development. www.ramsar.org

What are wetlands? Wetlands include a wide variety of habitats such as marshes, peatlands, floodplains, rivers and lakes, and coastal areas such as saltmarshes, mangroves, and seagrass beds, but also coral reefs and other marine areas no deeper than six metres at low tide, as well as human-made wetlands such as waste-water treatment ponds and reservoirs.

Ramsar Regional Center - East Asia: The Ramsar Regional Center – East Asia (RRC-EA) is one of the regional initiatives formally recognized by the Ramsar Convention. It serves as a regional platform for international cooperation, networking, funding and capacity building, and assists countries in East, Southeast and South Asia in implementing the Ramsar Convention. www.rrcea.org

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1. Introduction

Who is this guidebook for?

This guide has been produced primarily to assist site managers and research staff in their preparation of monitoring programmes at Ramsar Sites, although it can be applied to any wetland being managed for nature conservation.

In a non-technical language, the guide initially outlines the core principles and step-by-step design elements of a best practice monitoring programme, then offers general guidance on the more common variables most likely to be monitored at a wetland, and how to manage the collected data. A non-exhaustive 'further reading' list is provided at the end of this guidebook should more in-depth information be required to write your monitoring programme.

What is monitoring and why monitor?

When we protect a wetland site for nature, we aim, over time, to maintain or improve the state of its key features – such as the species, communities and habitats it supports, or the services it provides to human society (such as food, recreation and clean water). Monitoring is the process of finding out whether we are achieving these aims, by measuring change in these features over time at our site. In order to manage a protected wetland, we normally want to know about changes in the pressures (threats) that are affecting its character and values, and whether we are effectively responding (with actions) to these pressures. In order to determine this, we would need also to measure the pressures and the management response over time; this also is monitoring.

Monitoring should also be considered in the context of a site Management Plan. This plan will typically identify the features that we value at the site. For each of these features, there will be a target (goal, objective), which describes the desired state (numbers, extent, health, etc.) we are aiming for, and indicators – which describe what we will measure in order to determine whether we have achieved our targets. The plan will also identify the pressures that apply at the site and the responses (actions) that are needed in order to mitigate the pressures, and achieve the targets.

As the plan is implemented, site managers need to know whether they are making progress towards the targets, and, if progress is not being made, they need to know why: is it because some of the pressures have not been reduced as hoped? Or is it because some of the responses have not been implemented as planned? If the site managers have answers to these questions, then they can adapt their actions to get back on track. A good monitoring scheme provides these answers and so allows adaptive management[1].

A Ramsar Site does not sit in isolation. It is part of several wider networks, such as the regional network of Ramsar Sites; the waterbird flyway upon which it lies; the set of sites that support red-listed species; the protected area network for the country in which it sits; the hydrological catchment; and the global wetland resource. All of these wider networks also have plans with actions and targets, and in order for conservation to work effectively, they need information about whether progress is being made. Site-based monitoring schemes are building blocks that, when put together, can provide this information.

Not all data-gathering or research is monitoring. It is important to keep in mind that site

1 Adaptive management is a stepwise process of integrating design, management, and monitoring in order to adapt and learn. Adaptively managing a Ramsar Site involves agreeing our targets at the outset, and describing our understanding of the system we are working in. Then, we plan and implement the management and the monitoring actions in a scientific way, so that we use evidence to test our actions and assumptions, and thus to revise and improve our plans. Ramsar Resolution VIII.14 on guidelines for management planning calls for this type of approach on Ramsar Sites and other wetlands.

monitoring serves a very particular purpose: it tells us about changes over time and the pressures on the site, the state of the site and our management responses; and, in doing so it facilitates adaptive management. There are many other reasons why we might want to gather data or conduct research. For example, we might have two options of management actions to improve a habitat, and are unsure which will be most effective. In this instance we might design an experiment to test which action works best. This would involve data gathering, and ideally it would be conducted scientifically, but it falls outside of site monitoring as we define it here: it is a stand-alone research project, designed to answer a specific question.

In summary, monitoring is a vital tool for management of your Ramsar Site. Ideally, it emerges from and informs the implementation of a Management Plan. The information will help to improve management of the site, but it will also scale-up and contribute to wider efforts to conserve wetlands.

Concepts, terminology and synonyms

It is important to be aware that different organisations and publications use different terminology to describe monitoring and its components. There are even different definitions of monitoring contained within different Ramsar documents. This section explains the terms we use in this guidebook, and how they relate to terminology used elsewhere.

Bold is for the words that we use primarily in this guidebook. Brown is for words used in Ramsar Handbook 13. Green is for words typically used in ecosystem service terminology.

Monitoring: the terminology around monitoring, surveillance and research is confusing and can be contradictory. Here we treat monitoring and surveillance as synonymous, meaning the measurement of change over time. Research has a broader definition, encompassing any activity that involves studying a subject to obtain new information or understanding.

Feature, Ecological character: the elements of the site that we wish to conserve and enhance. These comprise (1) attributes such as *species, biological communities, habitats* but also cultural and heritage features; (2) processes (broadly corresponding to supporting ecosystem services); (3) functions (broadly corresponding to regulating ecosystem services); (4) products such as food, water (provisioning ecosystem services); (5) values (broadly corresponding to cultural ecosystem services).

Baseline: the original state of the wetland and its features against which we measure change over time. The baseline can be what we think the site was like before human impacts, or at some more recent point in time, such as when the site was designated or the Management Plan commenced. For Ramsar Sites, the baseline would typically be the ecological character of the site as described in the Ramsar Site Information Sheet at the time of designation.

Target: the desired state of the features of the site (sometimes referred to as an *aim, goal* or *objective*). The target may be to remain at or return to the baseline. However, if the aim is to restore a site from a degraded state then the target may be very different to the baseline. A target is often a broad, sometimes subjective or qualitative statement of how we would like the feature to look (for example, we would like a threatened species to have 'recovered'). An **indicator** is a way of quantifying progress towards the target (for example, the number of individuals of the species that we consider would show that it has recovered).

2. Wetland monitoring - principles and design

Deciding what to monitor

This is probably the most important step of all. There are a more or less infinite number of things that *could* be monitored, but resources are finite so it is vital to be focused on those that matter. Tough decisions about what to leave out of a monitoring scheme are almost always necessary.

Ultimately, the things we monitor are **variables** – such as number of birds or extent of habitat. In deciding which variables really matter to us, we need to refer back to the purpose of monitoring – to provide information about change over time that will allow us to track progress towards our targets. In addition, for those targets that we are not achieving, we want to understand why, so that we can improve our management. Therefore, we should only monitor things that matter towards our targets. This may seem obvious, but sometimes things are monitored because they can be, not because they should be.

In designing a site monitoring programme, a helpful framework to decide what to monitor is to think in terms of **pressure**, **state** and **response** (PSR). Pressures are the human-caused *threats* to the site. State is the condition of the features of the site. Response is the action we are taking to manage the site. This framework, which is used by BirdLife International to monitor Important Bird Areas, fits well with most management plans, because they will typically identify the desired state (the target), the pressures that we think are likely to need addressing, and they will propose a series of actions (responses) that we think will reduce the pressures and improve the state. An extension of the PSR framework is Drivers, Pressure, State, Impact, Response (DPSIR), which is used by, for example, the European Environment Agency. In DPSIR, we separate underlying *drivers* (such as tourism, climate change) from direct *pressures* (e.g. disturbance, drought). We also distinguish *state* variables (e.g. fish populations) from *impacts* of the pressures (reduced income from fisheries).

WWT staff carrying out soil sampling for Common Scoter research in Glengarry, Scotland

Historically, monitoring schemes often focused mainly on the state. For example, if a key feature of the site was the non-breeding waterbirds, then monitoring would concentrate on waterbird counts. This is clearly necessary: if there are targets in the Management Plan for the number of waterbirds at the site, then by counting waterbirds we will find out whether we have met the target. However, a PSR approach extends and strengthens this. For example, if we believe that human disturbance affects the number of waterbirds at the site, and we would like to reduce this pressure, then by measuring human disturbance over time we can find out whether we have succeeded in this management target. And if we believe that regular patrols will reduce the disturbance, then monitoring how many patrols we did will tell us whether we implemented the response as we intended. By doing this, we can adapt our management: if waterbird numbers do not meet the target, we can ask ourselves whether it was because we failed to reduce disturbance. If we failed to reduce disturbance, we can ask ourselves whether that is because we didn't take the patrolling action that we intended. We now have a much richer set of data with which we can gain deeper insight and make better decisions.

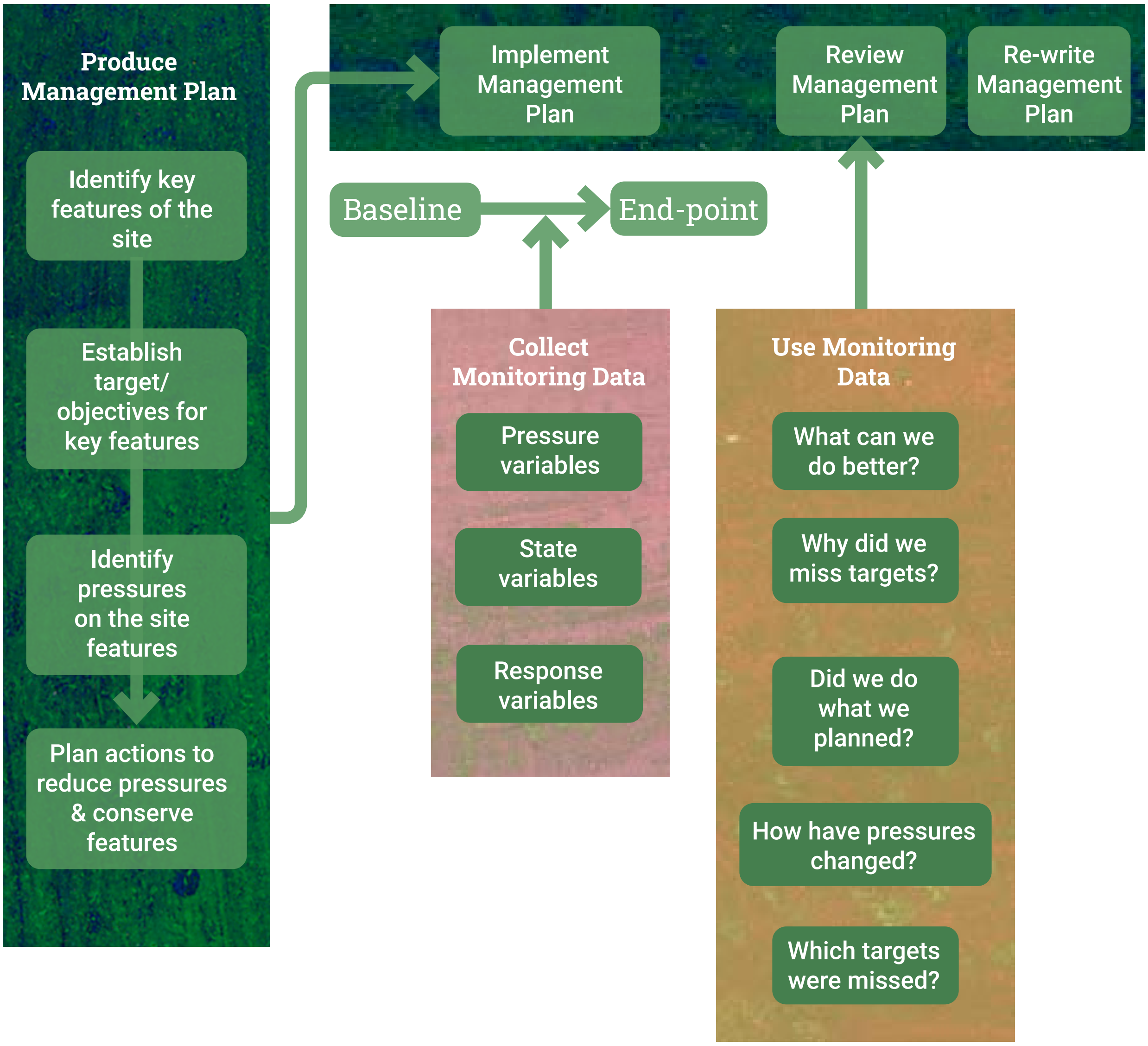


Figure 2.1. The relationship between site monitoring and the process of site management planning.

Who do we report to?

The fundamental reason for monitoring is to support the management of the site, and a monitoring scheme should be designed with this in mind. However, as part of designing a monitoring programme it is useful to consider who else needs to know about what is happening at the site, what they need to know about, in what detail, and how often. This can be complex: the information is requested across multiple spatial scales, and for different features such as migratory birds and threatened species, among others.

Considering this at the outset can help shape the monitoring programme. It can allow you to find efficiencies where one monitoring job can be carried out to fit several purposes.

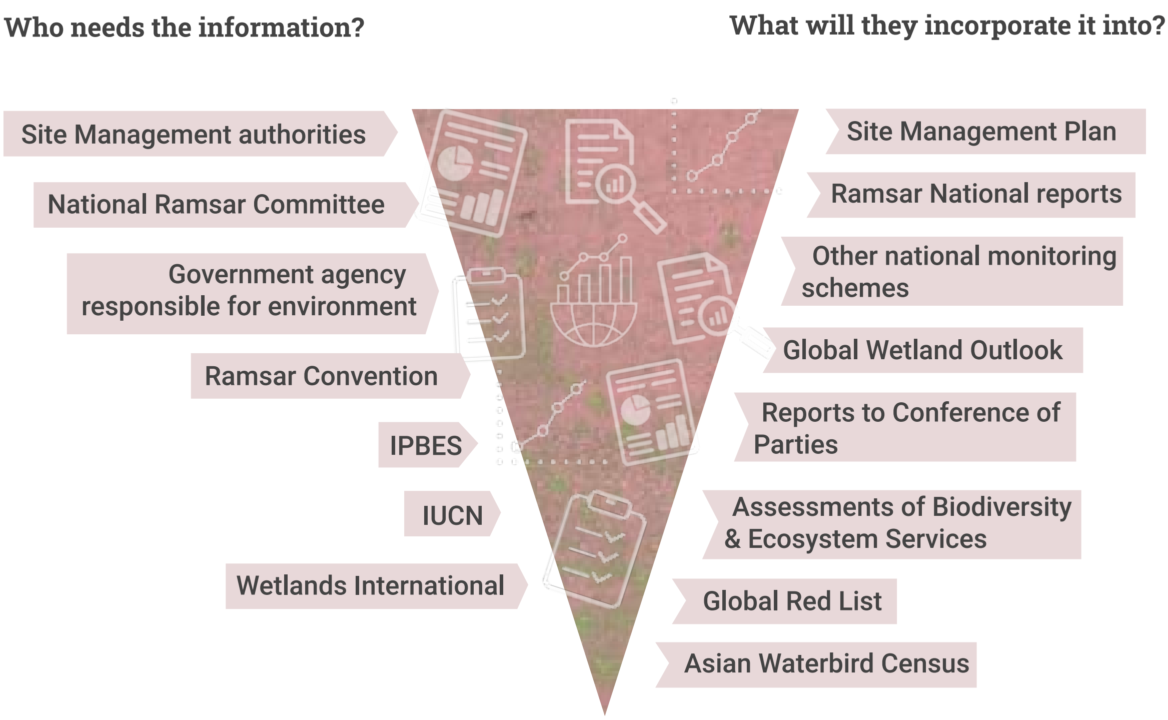


Figure 2.2. A hierarchy of data use for monitoring data from a Ramsar site. This is indicative: there are multiple other potential users of the data

Scientific principles of monitoring

Being scientific in your approach to monitoring does not mean that your work must be highly complex, high-tech, expensive or time-consuming; nor does it mean that you need advanced statistical analysis. Rather, it means that there are some basic ways of approaching the task that will give you confidence that the data you collect are robust, and will allow you to draw valid conclusions about how the site is changing over time.

Because the monitoring programme is about identifying *broad patterns* of change, there is often no need to be (and usually we cannot be) perfectly complete, accurate and precise in our data collection. In fact, being precise and accurate *enough* to be able to tell whether a change is real is key; much more detail than that is probably wasting valuable resources. Because monitoring is about detecting change *over time*, it is more important that the data are collected in a consistent manner over time than it is for them to be complete and precise. It's also useful to recognise that we cannot measure everything that is happening in the very complex socio-ecological system that is a Ramsar Site, and we shouldn't try to. Instead, we can select variables that act as proxies or indicators of what is changing over time, capturing the key trends in a simplified way.

Repeatability

This is the single most important principle to keep in mind. The best way to make sure that your comparisons across time are valid is to make sure that, whatever variable you are measuring, you do it *in the same way* on each occasion. You want to have as much confidence as possible that any change you are detecting is real, and not caused by changes in how, where or when you did the data-gathering. There are various ways to ensure that this **standardisation** happens:

- Clearly document the series of steps/methods being carried out, including the equipment used, the personnel, time and location, so that you can refer back to this on the next occasion and do the same thing again.
- Match the methods to the resources you have available now and are likely to have in the future. Do not start by gathering data very intensively if you are unlikely to be able to sustain this level of detail in the future.
- Similarly, think about making the methods resilient to changes in the people you have available to employ them. Is your monitoring entirely dependent on one expert who knows the method? If so, do they need to train a colleague? Or do you need to try something simpler for better future-proofing?

Variability, replication and frequency

Some variables vary over short time-periods or across a site. Others are hard to measure accurately, so that there tends to be measurement error. If this variation and error is very large, it can be hard to detect systematic change in a variable over time. If we cannot detect change with confidence, then the monitoring has little value.

Replication means taking multiple measurements in order to obtain an average that will smooth out variations between times and places, and those caused by measurement error. This might mean taking measurements at multiple places within the site, or in the same place several times over a short time-period. The more variation there is in the variable, the more replication you will need to get an average that you can have confidence in.

However, if you pay attention to **repeatability**, you can remove the need for some replication. For example, while water chemistry may vary greatly across your site, as long as you measure it in the same place each time you do your monitoring, this is not necessarily a problem.

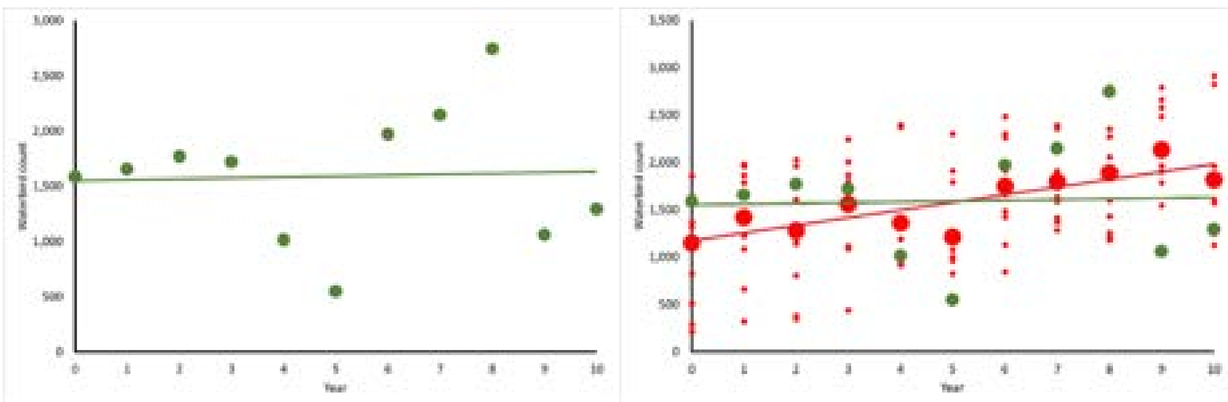


Figure 2.2. The value of replication. An example of monitoring an increasing bird population that is hard to count, giving counts that fluctuate greatly within a year. Left panel: a single count is taken per year (green circles), but each count could be a long way from the real average. Because of this, and by chance, the overall trend looks like no change (green line). Right panel: 10 replicate counts were taken per year (small red circles), and an average is taken (large red circles). This allows the underlying increase to become clear.

Sampling, bias and representativeness

Very often when monitoring a feature of interest, we do not need to achieve complete coverage across the entire site. For example, if the aim is to estimate the density of amphibians, there is no need to count every individual frog. If we wish to know about bycatch of turtles in fishers' catches, we do not need to account for every single turtle caught. Instead, the sensible approach is to take a **sample**. In the frog example, we might conduct several transects at different places around the site, but we do not attempt to cover the whole site. In the bycatch example, we might ask a selection of the fishers to report their bycatch.

In doing this, we must hope that the changes that we detect from our samples reflect - are **representative** – of what is going on at the site as a whole. This is where careful thinking is required. If the sampling is not representative, then we might generate biased data and draw the wrong conclusions. As an example, if we consider a site has a core zone that is well conserved, but a periphery that is negatively affected by activities outside the site. If our amphibian counts are only conducted in the core zone, we might conclude that frog populations are stable, but this would be because we have chosen a non-representative sample, and created a bias. If we sample the site in a representative way, by placing some transects in the core and some in the periphery, then we would perhaps see that there is in fact a declining trend overall. The same problem might arise if we only interview the fishers that we know well: their bycatch might decline over time because they are positive towards trying to reduce it, but among the overall community of fishers, including those who have not engaged with conservationists, the trend might not be so favourable.

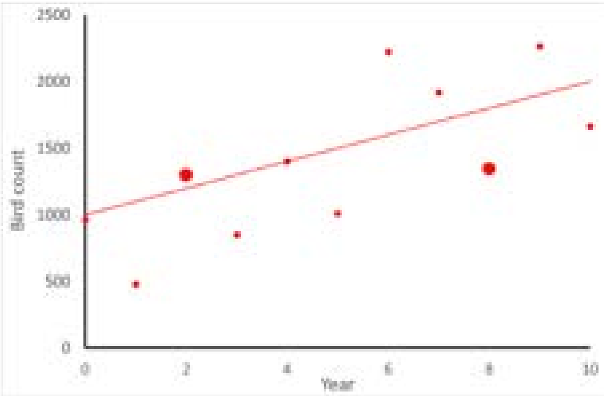
So, it is useful to think about the total set of places or people that we *could* measure for a given feature, and try to sample in a way that will be representative for the whole site. Random or systematic sampling is a way of achieving this. Random sampling would mean deciding that we will place our amphibian transects at random across the site, or that we will ask 10 random fishers about their bycatch. Systematic sampling can be an adequate alternative to random sampling and is sometimes easier to implement: we might divide the site into a grid and run one amphibian transect in each grid cell; or interview every tenth fisher about their bycatch.

An often-overlooked way of inadvertently creating bias is by selecting the 'best bits' as your monitoring sites at the outset. It is tempting for example, if selecting sites to monitor breeding birds, to pick areas where we know they are present/abundant. This certainly can make monitoring more rewarding: it is quite tedious to go to lots of areas where the birds are absent. However, even if the population abundance is not changing overall, it is quite normal for populations to shift to some extent over time. Patches that were unoccupied become occupied and vice-versa, just as a result of natural habitat change. If we have selected only good patches at the start, then we will tend, on average, to see their populations' decline, while other patches that we are not monitoring get better. We then might wrongly conclude that the population is declining. The solution is to select a set of patches at the start that includes both good and poor populations (e.g. pick patches at random).

Frequency

The core aim of monitoring is to detect change over time. This means repeated (and repeatable) measurements. But how often should they be repeated? This will vary enormously according to the feature that is being monitored and the method being used. The key over-arching consideration is to ensure that you monitor frequently enough to be able to distinguish between fluctuations over time and trends over time.

If the feature you are measuring shows large 'natural' fluctuation over time then you will need to monitor more often in order to determine whether there is a real trend or merely fluctuations in the data.



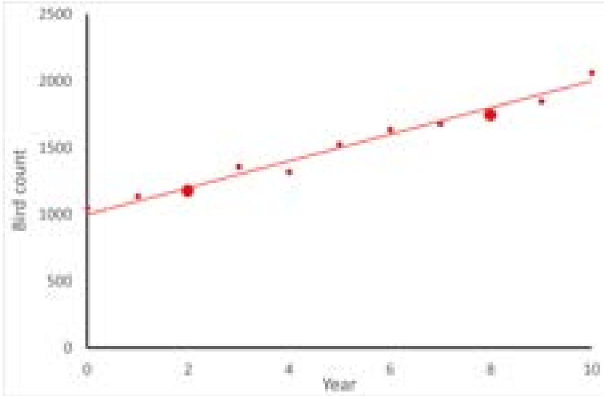


Figure 2.4. The importance of monitoring frequency. Counts of a fictional waterbird which has an increasing trend, such that at the start of the period there is an average of 1,000 birds, and at the end there are 2,000. The left panel shows a situation where the population fluctuates a lot between years, the right panel shows a population with low fluctuation. Both populations have the same underlying increase.

In the fluctuating population, if we count every year we can still detect the underlying increase. But if we counted infrequently (e.g. only in years 2 and 8 – the highlighted counts) then we can see that we might fail to detect the increase: by chance, year 2 was a 'high year' and year 8 was a 'low year'. In the low fluctuation population, counting every few years would save effort and still show the increase, because individual years do not deviate much from the overall trend.

However, if we only have a very small number of counts (e.g. only counts for years 2 and 8) and no other information, we could not safely conclude whether we are seeing a trend or a fluctuation. Before we can decide how frequently we should count, we need to know something about how variable the counts are between years.

Practical and logistical issues

The design of monitoring schemes is as much about practical considerations as it is about scientific ones. A perfect scientific design will fail if you have not planned how to implement it in the real world.

The most obvious consideration is the resources you have available to deliver your programme, in terms of people, money and equipment. Resources spent on monitoring cannot also be spent on actually managing the site. On the other hand, if good monitoring leads to better management of the site, then it will be money well spent. Monitoring is not a luxury item, it is an essential part of good site management, and management authorities should resource it accordingly. Whatever resource is available, it is vital that you design the monitoring programme to fit what you have, not what you wish you had. Keep in mind that monitoring requires consistent effort over time, so fit to the resources you can sustain, not to what you might have in year 1.

Another key resource to consider is expertise. There is little advantage in designing complex programmes that require highly specialist skills if you do not have long-term sustainable access to those skills. Many highly effective monitoring methods are simple and low-tech. Remember that you are often looking for simple indices of progress, not precise measurements, so always ask: how much is good enough? You do not need more than that.

It is important to think through the resourcing and implementation of the whole monitoring programme, not just the data collection. Organising and directing the work beforehand (including taking care of issues like health and safety) can use up significant time. Even more time-consuming can be data-entry, management, analysis and reporting. This should be factored in when planning and budgeting for the work.

The resources you have for monitoring are probably not fixed. There are ways to get more for your money. Think laterally about how you might increase monitoring capacity. Is there potential to use citizen scientists? Students from local universities who want to gain experience? Are local academics looking for useful and interesting projects to support? Note that the recruitment and management of citizen scientists and volunteers is itself time-consuming.

Getting a wider group of people involved in monitoring can bring wider benefits. It can be a way to increase support for the site more widely. Participatory monitoring by local people – especially site users – can be very powerful. People are more likely to value and believe the information if they collected it, and to feel a sense of involvement in the site's future.

It is worth thinking about what data already exists for the site and/or is already being gathered by other people and organisations. These data can be useful assets for your monitoring programme. For example, is there a hunting organisation that keeps records? Is there a water authority that measures water quantity and quality? If so, can the data be incorporated into your site monitoring?

It is also often possible to gather monitoring data 'incidentally' in the course of other work or to use data gathered for other purposes. For example, if rangers regularly patrol to observe human activities around the site, then there might be opportunities to create simple indices of human disturbance by simply asking them to write down the number of encounters they have with, for example, hunters, fishers or people undertaking leisure activities. Here, the data are gathered by people doing their normal tasks, with just slightly extra work needed.

Finally, it is important to remember that wetlands sit within, and are influenced by wider catchments; this is reflected in the Ramsar treaty itself. As a result, some monitoring might best be done at catchment-scale, or at least outside the boundaries of the Ramsar Site.

Steps in designing a monitoring programme

Determine the features you wish to monitor. If possible, refer to the Management Plan. Also use other key documents such as the Ramsar Site Information Sheet and information from, for example, IUCN Red List, East Asian Australasian Flyway Partnership, Wetlands International, plus national prioritisation exercises. Use a pressure-state-response framework – what are your most important threats (pressures), what are the key features that are important to your site (state), what are the main management actions you are planning (response).

For each feature you wish to monitor, determine how you will monitor it. **What will be the variable to be measured?** There are often multiple options available. If possible, review the state-of-the-art: what are other people and organisations doing? Also, consider what information is already available (see above). In general, start from a principle that simplicity is best and cheapest. Simple information is also often easiest to communicate to stakeholders.

When you have decided what variable to measure, then decide on the **protocol for measuring** that variable. Here you would consider how often and where sampling is done, plus the people and equipment involved. At this point, you will be able to assess the resources needed in terms of people and money, and other logistical considerations such as safety, permissions and training. It is vital at this point to consider how the data will be managed, analysed and reported. It is not wise to gather a lot of data and only then start to think about how it will be handled.

At this stage in the process, you might have a long list of features, variables and draft protocols. It is here that you probably want to **review the plan and adjust it to fit** to the resources available. If you have got too much on your list, you will need to prioritise the truly critical over the merely useful.

After this, an **operational plan** can be produced. This will set out the complete programme, including the detailed protocols, and make the lines of responsibility for implementation clear.

Implement the programme. This might involve some baseline measurements, followed by the repeated iterations of data gathering ('*monitoring occasions*') over the time-period of the programme.

Report, and use the reports to **improve site management**. This is of course the fundamental reason for doing all the monitoring. The test of whether the monitoring has been appropriate and useful is whether it is periodically used to inform changes in site management. For example, it might show that one of the pressures on the site has increased, and requires more management response, or that one of the key species at the site has increased and is no longer such a high priority for action.

3. Data collection

Pressure variables

Water chemistry

Water physico-chemistry is critical to wetland ecosystems. The 'natural' water chemistry – determined by geology, hydrology, biological productivity and climate – will have a fundamental influence on the characteristics of the wetland (e.g. saline, brackish or fresh; oligotrophic, mesotrophic or eutrophic). Pollution caused by humans is one of the most universal pressures on wetland ecosystems. It is therefore quite likely that some aspects of water physico-chemistry will be important aspects of your monitoring scheme. However, these are not necessarily cheap or easy variables to measure, so it is important to consider which pollutant types are relevant to your site, and focus on these. Organic pollution, eutrophication and sediment are often closely linked in cause, impact and measurement (see Table 3.1).

Alongside measurements of physico-chemical variables, the impact of pollutants is sometimes also measured using biological variables: the presence of abundance of particular species or communities that are sensitive to the pollutants is measured. However, this is only possible in well-studied ecosystems.

Table 3.1. Main types of water pollution, their sources, impacts and indicator variables.

Type	Origins	Ecological effects	Indicator variables
Organic pollution	domestic sewage, aquaculture and farm waste	Reduced dissolved oxygen Reduced light levels	Biological Oxygen Demand (BOD) Dissolved Oxygen Turbidity Conductivity
Nutrient enrichment (eutrophication)	Domestic sewage, aquaculture and farm waste; Fertilisers used in farming and forestry; Atmospheric deposition (from intensive animal rearing and fossil fuel combustion)	Algal dominated food webs Toxic algal blooms Reduced dissolved oxygen Reduced light levels	Nitrate Phosphate Ammonia Dissolved Oxygen Turbidity Conductivity Chlorophyll
Sediment	Soil erosion from poor farming and forestry practices, and construction	Reduced light levels Smothering of benthic animals and plants	Turbidity Suspended Solids
Pesticides	Agriculture, forestry and aquaculture	Directly toxic to some aquatic life	Specific laboratory assays
Toxic (industrial) chemicals	Discharge and leaks from various industrial processes and mining	Directly toxic to some aquatic life	Specific laboratory assays pH
Saline intrusion	Sea-level rise, groundwater pumping	Shift to salt-tolerant species	Conductivity Salinity
Heat/temperature	Cooling water from power stations Climate change	Shift to high temperature tolerant species	Temperature

This table is not intended to be exhaustive.

Whilst some water chemistry variables can be measured in the field with hand-held probes, for some variables, further analysis is required. Your priorities and the resources available will determine the variables selected and the type of analysis undertaken.

Table 3.2. Suggested equipment and methods for measuring water chemistry variables.

Variable	Field measurements			Laboratory analysis	Remote sensing
	Logger	Handheld probe	Test kit		
Temperature	✓	✓	-		
pH	✓	✓			
Alkalinity	×	×	×	✓	
Conductivity	✓	✓			
Turbidity	✓				
Dissolved oxygen	✓	✓		×	
Ammonia				✓	
Nitrate				✓	
Phosphate	✓			✓	
Suspended Solids				✓	
Metals	×	×	×	✓	
Pesticides	×	×	×	✓	
Chlorophyll a					✓

Design

It is important to set up water sampling monitoring points that are accessible throughout the year and that can be relocated readily. When using hand-held loggers, it is important to take the reading from an area with sufficient depth to immerse the probe whilst also minimising disturbance to the water column and sediments. A sample of water can be directly collected into a container using a simple pragmatic method such as a jug attached to end of a pole. This equipment also allows the sample to be taken from a well-mixed area of the wetland without disturbing and suspending the sediment. For samples that need to be transported to a laboratory for analysis, storage needs to be considered. Samples should be kept cool and transported as promptly as possible to the laboratory as some types of analyses need to be carried out within a short time of sampling.

The number and location of sampling points required will depend on the size and complexity of your site, where you think the pollution originates, and how widespread you think its effects might be. The frequency of sampling also depends on specifics of the site. Some water chemistry shows distinct seasonality (e.g. sediment load high during high water flows; eutrophication and organic pollution impacts greatest in low water levels and high temperatures). Some polluting events are irregular and brief but have longer-lasting impacts. Monthly sampling is a good starting point, but it is difficult to give general guidance on this. Best practice is to take several readings (normally three) on any measurement taken in the field to ensure accuracy. When using field test kit and/or in the laboratory it is advisable to run tests in replicate and/or use standards (known concentration reference samples).

Water quantity and hydrology

The depth, extent and flow rate of water in a wetland, and the temporal change in these variables – shapes the ecology of the site. Hydrological change over time has profound effects on vegetation communities and consequently on the species supported and the ecosystem services provided. Climate change and human activities in catchments are important pressures that affect hydrology. For example, upstream dams or water abstraction for agricultural use can reduce downstream wetland water levels. Urbanisation and deforestation can make water run off a catchment quicker, creating more variable water flow.

Whether and how you monitor hydrology varies enormously, depending on the type of wetland you are monitoring, and how it is being affected by anthropogenic pressures.

In flowing (lotic) water, the typical variable of concern is flow (discharge), which is the volume of water moving past a given point per unit time. Very often, we can simply measure the height of the water at a fixed point using a fixed stage-board as a measure of relative flow rate. Automatic logging of water levels is now possible using pressure sensors (often called divers). These provide high-frequency measures over long time-periods, but are expensive. Water levels can be converted to a true discharge estimate by calibration; to do this we need to measure channel cross-sectional area and current velocity, under different water levels. In smaller streams, the cross-sectional area of the river or stream can be standardised by installing weirs. In-stream Acoustic Doppler Current Profilers (ADCP) are now available to automate flow measurements; they are expensive but labour-saving.

For still (lentic) waters, depth/extent of water are the key variables. Depth can again be simply monitored using fixed stage-board measurements or divers. Depending on size of wetland and resources available, surface-water extent can be monitored using fixed-point and aerial photography, satellite imagery, or by simply using people to map the extent of water coverage. For ephemeral wetlands, it can be very useful to monitor the duration of dry and wet periods. Alongside direct observation and fixed-point photography, digital loggers that record conductivity (high when flooded, low when dry) are increasingly used for this purpose. Unmanned Aerial Vehicles (UAV's) are a relatively new, powerful and increasingly affordable for mapping water extent over time.

Groundwater levels and soil moisture are important to the ecology of some wetlands, because they affect nutrient cycling and vegetation communities; many animals also require moist soil at various life stages. Dipwells are the most frequent way of measuring groundwater levels. Soil moisture can be measured by taking soil samples back to the laboratory and drying them to measure water loss; various water moisture probes are available for in situ measures.

Notwithstanding sea-level rise, tidal waters tend to be predictable in depth and extent, and are less likely to need monitoring for change over time.

The optimum frequency and spatial spread of water quantity measurements should primarily be determined by thinking about how dynamic the system is, and which specific pressures you anticipate.

(Picture credit) Groundwater level monitoring using a dipwell, Boeung Prek Lapouv Protected Landscape, Cambodia

Harvesting, hunting and bycatch

Many people take essential life-sustaining resources from wetlands by extracting food, fresh water, wood, fibre, fuel, to name a few. As part of this offtake, bycatch occurs as the unintentional trapping of non-target species (for example waterbirds, turtles and cetaceans caught in fishing equipment). Long-term, unsustainable offtake through harvesting, hunting and bycatch can lead to species, and wider ecological, decline; it is especially problematic in areas where threatened and protected species are present. As a site manager, it is important to monitor the level of offtake. Offtake may be legal and regulated, or illegal and unregulated (poaching), but in all cases it can be a sensitive matter with local communities, and so needs to be monitored with caution; good consultation is especially important in this process.

If monitoring activities identify unsustainable or illegal offtake, suitable mitigation processes or actions should be included in the Management Plan.

Design

We might wish through to obtain a complete count of offtake of key species, but in most cases a relative index of the pressure is sufficient, and there are various indirect measures of obtaining this. Monitoring might take place at one or more of the different stages of the offtake process:

1. The activity itself (e.g. directly monitoring how much hunting, fishing, harvesting takes place);
2. The end-use of the offtake (e.g. how many products of offtake are in markets); and
3. The impact on the target species’ populations (e.g. through broader population monitoring).

Communication, capacity building, education, participation and awareness (CEPA) activities can be used to sensitively gather information – e.g. through questionnaires or participatory methods - on trends in hunting/harvesting practices. These activities can simultaneously be used to raise awareness of unsustainable offtake. Harvesting/hunting practices may be an important source of income or food, so you should be aware that community consultations, monitoring and subsequent interventions may elicit tensions or conflict with local communities. In such circumstances, consider using monitoring activities that enable the community to contribute information anonymously. If positive relationships are established with the community, and they feel that good site management can benefit their livelihoods, then they can become valuable contributors to monitoring because they see it as being in their interests to regulate offtake.

A variety of other methods to monitor bycatch and offtake are available. If the site is patrolled to detect and deter illegal activity, then records from patrols can be a useful index of how much hunting and harvesting pressure there is. Indirect indices of the amount of pressure can be obtained, for example from the number of shots heard or traps found. Where offtake such as fishing or hunting is licensed, records of the numbers of licenses issued can be used.

Note that for some offtake, it is not just the number of organisms that are taken, but also the methods used – for example, some fishing practices are more destructive than others. Similarly, the age/size of the organisms that are taken can be important; for many species, offtake of mature females is more harmful to the population than offtake of juveniles. This needs to be borne in mind when designing monitoring.

Human disturbance

By human disturbance, we here refer to the direct effects of human presence on animals through scaring them so that they stop their normal behaviour; or displacing them from sites they would normally use.

Human physical presence and activity is a potential pressure at some wetland sites, because it has the *potential* to negatively affect wildlife. It is tempting therefore to monitor the amount of human activity and treat that as a simple indicator of disturbance at the site. It is important to remember however that the amount of human activity does not necessarily indicate how much of a negative effect it is having on wildlife. Many animals are extremely tolerant of human presence. In designing a protocol to monitor this pressure, it is therefore important to consider specifically which locations, timings and key species you are concerned about. For example, breeding colonies of waterbirds and high tide roosts can be sensitive to disturbance, whereas when the same birds are feeding in the wider wetland they are unaffected by human presence. Similarly, unpredictable, rapid or noisy activities such as water-sports tend to be much more disturbing than predictable, slower activities such as fishing.

Design

In general, it is relatively straightforward to measure indices of human presence and activity. It is very difficult to rigorously monitor the impact on wildlife: estimating how much human activity is displacing animals from sites they would otherwise use is scientifically complex.

The first and vital step is to determine what type of disturbance pressure you are concerned about, and where, when and for which species it is a concern (see above). Then build your monitoring protocol around this specific pressure.

It is technically simple to record the numbers of people present at a site and the activities they are engaged in, however, it is also potentially very resource-hungry, taking a lot of staff time. Therefore, we recommend thinking of ways to measure the pressure using simple indices and integrating its measurement into other site management activities. For example, you could ask site rangers to keep a simple record of how many disturbing activities they see in the course of their normal work. If camera traps are being used to monitor mammals, they could also be used to monitor human presence. Sometimes 'signs' of human disturbance can be easier to monitor than the direct presence of humans, for example if the disturbing activities occur only briefly or are conducted secretively. Tire tracks, fire pits, footprints can all be used in this way. In some places, it may be possible to use some very lateral thinking: numbers of tourists in local hotels may be a good disturbance indicator if tourists are perceived as the main disturbance pressure. It may even be possible to use numbers of internet searches to quickly find out about this sort of pressure.

Invasive species

Invasive species are a major pressure on many Ramsar Sites, and as such they need monitoring. They are of course enormously varied, covering almost every conceivable taxon. Not all invasive species are necessarily a major problem. It is important to prioritise those taxa that are known, or are likely, to threaten the values of your site.

Taxon-specific monitoring methods for invasive species are essentially covered under the monitoring of biota (below). In some situations, early detection of colonisation and spread of an invasive species might be particularly important. Species are hard to detect when rare, and aquatic species often particularly so. Environmental DNA techniques have been used with success for early detection of aquatic invasives and we recommend considering these. In other situations, such as cord grass (*Spartina alterniflora*) invasion in inter-tidal areas, or *Mimosa pigra* invasion on floodplains, the invasive becomes entirely dominant in the vegetation community, and monitoring will involve mapping areas of occurrence, rather than detecting presence or counting individuals. Some invasive species affect the ecosystem services upon which people depend. For example, water hyacinth mats can severely impact fishing. In such situations, and where the species is relatively simple to detect, there can be a strong case for using citizen scientists to monitor. This can generate powerful data as well as increasing a sense of participation in solving the site’s problems.

State variables

Habitat extent and quality

In some situations, the extent and quality of particular habitat type(s) is a feature of interest in its own right. In other cases, a particular habitat is valued because it is required by a species that is a key feature of the site, or because it delivers a particular ecosystem service (including to local resource users).

For the purposes of site monitoring, habitats are usually divided into discrete categories, even though this is necessarily a simplification, and transition zones between habitats can be very important in themselves. There are numerous wetland habitat classifications in use. It will usually be sensible – especially from the point of view of combining data across sites – to use an existing classification that is relevant to your region and wetland type. Ramsar's 'classification system for wetland types' is a useful starting point, but is very broad in scope and describes habitats mainly in terms of their *biophysical* characteristics. In many cases, we will want to monitor the *vegetation communities* that characterise our habitats. However, habitats are classified, their definitions must be clear at the outset, and consistently applied, in order to create a repeatable monitoring system.

Once habitat classification is agreed and unambiguously described, the habitat classes can be mapped at broad-scale using remote-sensing, such as satellite images or aerial photography. Ground-truthing is an important and often resource-hungry component of this. More simply, it is possible to map habitat extents by direct observation at ground-level, with the help of hand-held GPS. Depending on the size, complexity and accessibility of the site, it might be appropriate to walk along habitat boundaries to create maps, or to sample habitat at fixed points across the site and generate maps from that. UAV's increasingly provide a cost-effective means of monitoring large areas relatively quickly.

Monitoring underwater habitats presents particular methodological challenges, although the principles remain the same. Various remote-sensing methods have been developed that can map, for example, underwater macrophyte and seagrass beds. Although these are not (yet) simple to use, where they are feasible, they do provide large-scale coverage that may not be possible by other means. SCUBA diving and snorkelling can be used in some areas, but can be dangerous and it takes a lot of effort to cover large areas. Where recreational diving occurs, it might be possible to use citizen science data to map underwater habitats. Underwater cameras are increasingly used, whether carried by divers, aboard boats, or left *in situ* underwater. They provide data as a permanent electronic record, which can be a significant advantage. One rather under-used underwater habitat monitoring method is sonar. Sonar 'fish-finders' are relatively cheap, and can be deployed from boats, to create transect-based mapping of water depth, sediment type and macrophyte abundance, generating objective and repeatable data.

When monitoring habitat quality, it is above all critical to pre-define what we mean by quality; this in turn should depend on what we value about the habitat (see above). We might believe that a certain hydrological regime (e.g. water depth, period of inundation) is desirable, and so we might monitor that as an indicator of quality in a particular habitat. Alternatively, the biological community might be important, for example presence of key species. Key species might include those that are believed to be indicators that the habitat is in good condition; those that are important resources (e.g. food) for priority species at the site; those that provide important ecosystem services to people. In selecting indicator species, it is important to consider the ease with which they can be monitored – for example, are they easily detected/counted – as well as their importance to the habitat. In some cases, we might use a more community-based measure of habitat quality, such as species richness; sometimes an indicator of complexity is important, such as heterogeneity of vegetation structure.

Clearly, there are numerous potential indicators of habitat quality and so we cannot summarise the appropriate methods here. However, whatever measures of habitat quality are used, simplicity and repeatability of measurement is key. Very often some form of repeated sampling of representative plots across the site forms a good basis.

In general, habitat extent and quality will change relatively slowly on a site, so typically your monitoring of this will be fairly infrequent. When considering the level of spatial detail that you aim for, you will need of course need to consider the resources available, but also the level of spatial precision that you need. Do you need to know if habitat extent has changed by a few hectares? Or is it only significant if it changes by tens or hundreds of hectares? Finally, remember that habitat change is natural and continuous in a healthy wetland. Open water succeeds to emergent vegetation and eventually to damp terrestrial habitat. Mudflats accrete and become vegetated, and saltmarshes erode back to mudflat. This means that loss of habitat in one area of the site may be balanced elsewhere. This means that, in order to assess change in net extent, it is important to monitor habitats across the whole site, not just in areas that support your key habitats at the start of your cycle.

Monitoring biota

Determining the range and abundance of key species at the site is often the core of a monitoring programme. This is because most Ramsar Sites are created to support important species, and they are usually a major indicator of whether the site is achieving what we want it to achieve. However, we repeat the warning that focusing only on the status of your key species is usually a mistake: adding information on pressures and responses greatly increases your ability to understand and respond to changes in the status of the species you are concerned about. Similarly, linking species monitoring to habitat monitoring can be very important, because it can give an understanding of why species' status is changing, and what management actions are likely to help improve matters. Overall, there is often a tendency to over-emphasise the monitoring of biota, and not give enough attention to other aspects of monitoring. We recommend careful thought about which taxa need monitoring and how much detail is required, based on a clear understanding of what the data will be used for.

Understanding the state of species' populations is likely to involve estimating abundance and distribution, but you should also consider whether other variables might be equally important. Some species live for a long time. They may appear to remain relatively abundant, but if they are not breeding successfully then there will be problems in the longer-term. In these situations, variables such as size of individuals, reproductive success and age-structure might be important.

Some animals are dangerous, and some monitoring protocols require nocturnal fieldwork. Ensure good risk assessments are completed and followed. Similarly, some sampling methods are dangerous or disturbing to the animals, and it is important to consider this factor in your protocols.

Birds

Bird census is a highly developed subject, with many and varied methods having been developed to handle the multiple different challenges that they present. Because many waterbirds are relatively conspicuous, being large, diurnal and using open areas, there may be a tendency to under-estimate the difficulty and importance of monitoring those species that are much more cryptic. A number of waterbird species are nocturnal and/or spend most of their time concealed within thick swamp vegetation.

There are several regional and global bird census programs, such as the Asian Waterbird Census, and you may wish to contribute to these; if so, you of course need to ensure you are using compatible protocols and timing.

Are you dealing with non-breeding waterbird congregations, or breeding populations? If breeding populations are the concern, you may wish to estimate productivity (breeding success) as well as the number of breeding birds. Passage migrants might only be present at the site for a short period, so counts need to be well-timed to capture the peak. However, the timing of peak non-breeding bird numbers may vary substantially between years (depending for example on weather conditions) and between species. This means that a single count on a fixed date every year, while it creates consistency, can give you very widely fluctuating counts and make it hard to detect an underlying trend in numbers. If resources allow, making periodic (e.g. weekly, monthly) counts through the key season can help resolve this problem.

Are the birds easy to directly observe – such as birds that congregate on open water – or more cryptic, such as birds that hide in swamp vegetation? The more cryptic birds tend to be under-estimated or ignored. You will have to decide whether and how to capture information about them: are they important for your site? Can you use a simple index (e.g. counts of vocalisations) rather than attempting direct counts?

There are usually particular periods in the diurnal cycle, the tide cycle or the seasonal cycle when the birds are much easier to detect and count. For example, shorebirds may congregate at one or more high-tide roosts, where the whole population can all be counted in a short period.

It is important to make sure that disturbance caused by counting does not have negative impacts on the birds themselves. This can be difficult to judge: birds are often relatively unaffected by being flushed away from their breeding, roosting or feeding areas, but too much disturbance can cause complete abandonment of breeding sites or displacement from roosts and feeding areas. Be cautious.

Many waterbirds are congregatory, and this makes estimating the number of individuals in flocks an important skill.

Birds are highly mobile, and therefore it is sometimes important to consider how to avoid double counting in multiple monitoring locations.

Rapid developments are being made in UAV (drone) technology to detect and count birds, and also in acoustic monitoring of bird vocalisations. It is worth considering whether these approaches might work at your site to monitor 'difficult' birds. Where there is an active birdwatching community, accessing data from e-bird or other citizen science repositories can be useful. Bird counts can also frequently be conducted by expert volunteers by connecting with birdwatching groups.

(Picture credit) A staff member bird counting at WWT Slimbridge

Mammals

Much more than birds, mammal census techniques differ massively according to the taxa being counted. This guide does not attempt to provide detail on the specific techniques, but we list them, so that you can consider the potential options.

In general, mammal surveying is difficult. Many mammals are nocturnal, shy and dispersed; the larger ones are usually rare. Some spend the vast majority of the time under water.

Table 3.3. Outline of main techniques for monitoring different types of mammal.

Type of mammal	Main methods
Bats	Acoustic monitoring Mist-nets and harp traps
Small terrestrial mammals	Trapping Tracking tunnels
Large terrestrial mammals	Camera-trapping Direct observation Identification of signs (tracks, dung, fur, burrows/nests, scratch posts etc) UAV surveys Hunter surveys
Fully aquatic mammals	Direct observation (from boats, planes, shore) UAV surveys eDNA Passive acoustic monitoring Fisher surveys

Camera-trap surveys can be a very efficient way to monitor medium and large mammals in habitats where they are nocturnal and/or hard to see (tall swamp vegetation, forest). There is a large and complex literature around how to use camera-traps in such a way that they provide the maximum of unbiased data for minimum effort.

Whether using camera-traps, or detecting signs, mammal surveyors often try to attract the target species into specific locations in order to increase the chance of detection. This is valuable because some species are so shy and dispersed that detections are infrequent. For example, salt licks and other food baits.

Similarly, detection of signs can be made more standardised and more frequent by using tracking tunnels with ink-pads to collect mammal footprints. These are often baited with food, but not in all cases.

For mammals that spend time in water, eDNA techniques may increasingly become a method of choice, though at present they largely detect presence/absence rather than abundance.

Hunters and fishers may spend a lot of time in mammal habitats and may be very familiar with some of the species; it is worth considering whether their observations can be collected and used to create monitoring data.

Herpetofauna

As with mammals, the enormous range of lifestyles, size and other attributes for herpetofauna means there are multiple monitoring methods. Identification can be very challenging for some of the species-rich groups.

More so than birds and mammals, and partly due to their need to thermoregulate, activity and therefore detectability of herpetofauna varies dramatically over short time-periods. For example, crocodiles may not bask if conditions are cool and cloudy; frogs may call much more during high humidity.

Some monitoring methods for herpetofauna, such as pitfall and funnel traps, involve capturing the animals and have quite a high risk of mortality to the captured animals. If this is a concern, then think carefully about whether and how to use these techniques.

Many terrestrial species can be monitored by placing artificial refuges (also known as retreats or cover boards) in their habitat for a period of time, and then checking in them/under them to count and identify the animals. There are many different designs, and some have recently been deployed in trees for arboreal species. Equivalent methods have also been used in aquatic habitats, such as mesh bags of leaf-litter and rocks that are used by salamanders. Artificial refuges have the distinct advantage of being a very repeatable, standardised method.

Table 3.4. Candidate monitoring methods for Herpetofauna.

Herpetofauna group	Candidate methods
Terrestrial and arboreal frogs	Direct observation transects (nocturnal) – visual and audio Passive audio monitoring (note: not all species call) Pitfall traps
Terrestrial salamanders	Artificial refuges Funnel traps
Terrestrial and arboreal lizards	Direct observation transects (diurnal) Artificial retreats Pitfall traps
Small terrestrial and burrowing species (e.g. Caecilians)	Pitfall traps
Crocodilians	Direct observation (usually nocturnal using eye-shine) UAV

Fish

Fish monitoring programs may gather information on changes in presence/absence of fish species at a site, abundance, or size distribution. The latter often gives important information about the health of the population and the impact of fisheries.

Main fish monitoring methods include:

- Direct observation by scuba diving or snorkelling; this is commonly used on coral reefs, but can be used in other habitats with good visibility;
- Direct observation from boat or shore using spotlighting;
- Live-catching fish through electro-fishing (though some countries do not allow this method);
- Capture with passive nets/traps – fyke nets, funnel traps;
- Capture with active nets - conical net trawls, seine nets, plankton nets (for fish fry);
- eDNA; and
- Citizen science – obtaining information from fishers.

Different methods will be better suited to different species or habitats, and some are better at providing relative abundance information than others.

Standardisation and repeatability of sampling effort is of course important. The standardisation might be in the number of passes made with a net or the length of time that traps are deployed for. Data are then normally presented in terms of 'catch per unit effort'.

Invertebrates

Wetland macroinvertebrate monitoring is typically challenging because we are dealing with species-rich communities for which taxonomic identification is often difficult, specialised and time-consuming. It can also be difficult to sample invertebrates quantitatively: they can of course be spectacularly numerous, but they can also show enormous fluctuations in abundance – or at least our ability to record them – over very short time-periods. However, invertebrates are critically important components of wetland ecosystems, and should not be neglected. Note that, like plants, some invertebrates effectively form habitats – for example bivalve beds and coral reefs – and can be monitored as part of habitat monitoring.

In most (but not all) cases, the conservation status of invertebrate species is poorly known, and they are not seen as charismatic flagship species. For these reasons, we are often most interested in community-based measures of the state of invertebrate taxa, such as species richness, gross abundance, or community 'type'. Certain invertebrate species are very important harvested resources, such as some bivalves, gastropods, decapods for food.

Invertebrate monitoring in freshwater and inter-tidal wetlands tends to focus on wholly aquatic invertebrates, such as many amphipod, decapod and isopod crustacea, bivalve and gastropod molluscs, and oligochaete and polychaete worms; or emergent invertebrates (those which have an aquatic larval stage and a terrestrial adult stage) such as Odonata, Ephemeroptera, Trichoptera, Diptera, Coleoptera and Hemiptera). In shallow marine wetlands, especially coral reefs, a rather different fauna of often large and conspicuous invertebrates are fundamental to ecosystem structure and function. Invertebrate community composition, or presence of certain taxa, can also be very good habitat condition indicators. In some instances, it is easier to record the effect of pressures on wetlands – particularly water quality – via their influence on invertebrate communities, rather than directly.

(caption) University staff sampling aquatic invertebrates at Kranji Marshes, Singapore

There is a confusingly large number of methods for sampling invertebrates in wetlands, depending on both the target taxa and the habitat in which they live. There is insufficient space to list them all here; instead, we emphasise the importance of deciding what you want to monitor and where, before deciding on the technique. These questions link to the over-arching question of why you want to monitor them: what will it tell you, what management changes might arise as a result of the monitoring? The initial questions to ask yourself when deciding on the method(s) to use are:

Which taxa or communities do I wish to know about? Each technique tends to be good at sampling some taxa, but poor for others.

Is the method intended to be quantitative (estimating abundance of one or more taxa) or qualitative (presence/absence)?

Beyond this, you need to think about the habitats you wish to sample:

In freshwater habitats:

- Is the habitat deep water, shallow water, wet soil?
- Is the sediment soft (clay, silt, sand), hard (gravel, stone) or solid (boulders, rock)?
- Is the water running or still?
- Are you sampling species in the air, on vegetation, in sediments or in water column?

In marine habitats:

- Is the habitat inter-tidal and therefore periodically exposed, or permanently inundated?
- Is the sediment soft (clay, silt, sand), hard (gravel, stone) or solid (boulders, rock)?

The great majority of sampling methods involve capturing your invertebrates, and then counting and identifying them. This can take a very significant amount of time, which needs to be factored into your planning.

Identifying invertebrates to species-level typically requires the specimens collected to be killed and preserved for examination under a stereo microscope. Identification to a higher taxonomic level (such a family or indicator group) can be done in the field and whilst the invertebrates are living, meaning they can then be returned to the habitat once identification and counting are complete. This can be a useful approach to take when working with volunteers/citizen scientists but does require guidance and training from a more experienced observer.

New approaches such as using environmental DNA samples have great potential to determine species presence and richness is relatively objective and repeatable ways. Because the identification is done in a molecular lab, there is also potential for relatively unskilled people, including citizen scientists, to take samples in the field, while avoiding concerns about sampling and identification expertise.

Invertebrate populations – perhaps most especially insects - show very large fluctuations over relatively short time- and spatial-scales, and this is an important consideration in how you sample them. You need either to sample in the same conditions each time, or take a large number of samples so that representative data emerges, or both. Aerial insect activity varies enormously with time of day and weather conditions. Some benthic invertebrate populations vary hugely on a seasonal basis, in line with seasonality in temperature and hydrology.

Plants

We discuss the monitoring of plant communities as part of the monitoring of habitat extent and quality above. Here we describe monitoring of plant species that are key features of the site in themselves. In some cases, where the target plant species is a dominant characteristic of the community (this might be the case for mangroves or seagrass for example) then the two ideas might merge.

How you monitor target plant species depends enormously on the type of plant, its abundance and conspicuousness. Clearly, some plant species are very visible throughout the year, whereas others are only apparent in certain seasons. Because plants do not move (!), they lend themselves to repeat monitoring at fixed locations where they are known to occur. However, when using this method, be aware of the inbuilt bias (discussed above) of starting your monitoring programme using only sites at which the species is present. Depending on the situation, it may also be sensible to include some monitoring plots that are unoccupied initially, so that you can detect colonisation events. More abundant plants are frequently monitored using some form of line transect or quadrat approach to generate consistent sampling.

It is important to decide, and be consistent about, the metric you will use to monitor your target plants. Depending on the abundance and distribution of the species, you might record number of individuals, frequency of occurrence in plots or area covered. For some plant species it might be important also to consider size or age distribution, especially if they are subject to harvest pressure. If mature individuals are key to reproduction or because they provide resources for animals, are they maintaining numbers, or is most of the population comprised of young individuals?

Sampling underwater plants presents particular challenges. Direct observation by SCUBA diving or snorkelling, or use of bathyscopes is one option. Underwater cameras are increasingly used. Use of grapnel hooks from boats can also be used to bring underwater plants to the surface.

Most plant populations are relatively slow changing, so monitoring can be fairly infrequent.

Ecological processes

Wetlands are dynamic systems. They consist not just of static physical and biological features, but also a set of biological, morphological and physico-chemical processes relating to geomorphology, hydrology, sediment, nutrient, species interactions and movements. Increasingly, we think of these processes as being valuable features in their own right. These natural processes are what make wetlands such productive and important ecosystems; however, human modifications often seek to stabilise them, for example, regulating water flow via dams, the installation of flood prevention measures or crop irrigation. Hence, monitoring of these processes can be essential for a full understanding of change in a wetland.

Wetland processes operate over different time scales:

- Short-term processes driven by diurnal cycles or short-term weather events
- Seasonal processes (within a year), driven by seasonal weather patterns and species life-cycles
- Long term processes (between years), driven by climatic variation

The first step in monitoring is to identify the processes that you believe to be important for the wetland's function, and therefore worthy of monitoring.

Table 3.5. Examples of wetland ecological processes and why they might be important features to monitor.

Process	Why it might be important
Hydrology	
Wet season connection of floodplain to watercourse	Maintains floodplain vegetation communities Allows fish to complete lifecycles Precipitation/rainfall pattern, water cycle regulation
Dry season drying of ephemeral pools	Supports specialist communities by preventing colonisation by competitors and predators
Nutrient	
Macronutrient removal and cycling by wetland plants and microbes	Reduces downstream eutrophication
Geomorphology	
Erosion and accretion in river meanders	Creation of early successional habitats
Marine sediment deposition in the inter-tidal zone	Replenishment of organic matter and nutrient
Species interactions	
Predation	Regulates abundance of herbivores
Grazing	Regulates abundance of dominant plants
Propagule dispersal by animals	Permits reproduction and dispersal of some plants

There is a strong overlap between some of these processes and the pressure monitoring of water quantity and quality described above, because they both relate to changes in water, sediment and nutrient at the site. Others are related to the monitoring of habitat extent and biota. Similarly, many ecosystem processes can also be considered as supporting or regulating ecosystem services. For that reason, we do not separately explain monitoring methods in detail here. We note though that scientists are increasingly realising that these processes underpin the wetland's ability to support wildlife and deliver ecosystem services, so they are worthy of attention.

Ecosystem services

Ecosystem services are the benefits that ecosystems provide to people. One aim of the Ramsar Convention is that policy-makers recognise the wide range of ecosystem services that wetlands provide, and reflect them in their decisions, policies and actions. For people who live near to the site, the ecosystem services it provides may be the principal reason that they value it and support its continued existence. Site managers, therefore, need to be able to identify changes in the services provided by their wetlands in order to influence policy makers.

As with so many of the features described in this guidebook, there are a very large number of potential services and numerous ways to measure them, and simply selecting the highest priorities for monitoring is a key step. For wetlands, the new Rapid Assessment of Wetland Ecosystem Services (RAWES) approach provides for a rapid scoping assessment of services provided and has been developed specifically to meet Ramsar reporting needs, so we strongly recommend its use, to help ensure replicability and consistency of results and comparability across sites.

RAWES is a rapid assessment tool, and so often used for one-off surveys. However, it can be used repeatedly for monitoring at a site. Nevertheless, it is a semi-quantitative technique and there may be occasions when you wish to measure some variables more quantitatively. We recommend that site managers focus in particular on the provisioning and cultural services, and the values that local site users are obtaining from the site, and many of these are inherently quantitative: how many fish, how many tourists, and so forth. If a more detailed methodology is required, Harrison et al. (2018) provide a framework for deciding between the vast range of assessment tools available. When thinking about ecosystem service monitoring, it is important to consider who and where the beneficiaries are. Is the service global, regional or local? Climate regulation is a global good, whereas income from sale of fish is local. Are specific sectors of local society benefiting from the service, or the whole community? Fishers might be the chief beneficiaries of fishing income, but whole downstream communities might benefit from fresh water and flood regulation. These considerations will determine who you question in participatory surveys.

Table 3.6. Examples of wetland ecosystem services.

Type of ecosystem service	Wetland examples
Supporting services	Primary production by plants and algae
	Soil formation by sediment accretion
	Nutrient cycling by nitrification/denitrification
Regulating services	Water purification by wetland microbes and plants
	Climate regulation by carbon sequestration
	Flood regulation by (for example) inundation of floodplains
Provisioning services	Harvest of wild animals and plants for food, medicine or fibre
	Fresh water
Cultural services	Recreation and tourism
	Spiritual wellbeing

Note that supporting services and regulating services heavily overlap with some of the variables we might measure under the headings of habitat extent and quality, biota, harvesting, disturbance and ecosystem processes

Response variables

Management responses

The monitoring of 'response' variables is often overlooked, but it can be a powerful tool. It really means tracking the conservation actions (interventions) you (or others) are taking at the site. In particular, it can mean tracking whether you actually took the actions that the Management Plan suggested were necessary. Consider the situation where a key species at the site declines over the monitoring period. It may have declined because important pressures on the site increased, in which case your monitoring on pressure factor will hopefully show that. But it may have decreased because the actions that were planned did not actually take place; in this case, response monitoring should indicate that. But it might have decreased *even though* the actions took place, in which case you might conclude that the actions were the wrong ones and adapt your management accordingly.

As with all monitoring, the response variables need to be relevant to the interventions that you need and planned to do for the site, which in turn depends upon the priority features and the perceived pressures upon them. This will of course vary enormously between sites; there is no standard template.

Table 3.7. Examples of how management responses to pressures on the site can be monitored.

Pressure	Proposed action
Invasive plant spread	Control invasive plants
Illegal hunting	Active policing of the site
Fishing bycatch of key bird species	Work with fishers to deploy bird-safe practices
Pesticides polluting waterbodies	Work with farmers to reduce pesticide use or reduce run-off into waterbodies
Human recreational disturbance of bird nesting areas	Introduce seasonal zonation and ensure the zones are clearly communicated

Specialist data collection methods

Earth observation for wetland monitoring

Earth Observation (EO) technologies, datasets and processing tools are more widely available and accessible than ever before. EO can provide frequent and comparable information on the ecological character of wetlands and offers a cost-effective means of monitoring over large areas.

The application of EO depends greatly on the specific variable to be monitored, the type of energy to be detected, the area to be covered, frequency at which measurements will be made, as well as practical considerations such as cost and expertise. While EO methods can reduce the need for labour- and time-intensive field surveys, most methods still require ground-based observations e.g. to aid and assess the accuracy of wetland habitat classification.

Design

Both satellite and airborne sensors can provide EO data at varying spatial, spectral and temporal resolutions, with many applications to wetland monitoring (Box 1). Satellites provide periodic information that is essential for understanding dynamic wetland ecosystems, while aircraft and Unmanned Aircraft System (UAS) offer a cost-effective means of collecting data at very high spatial and temporal resolution. Sensors that detect beyond visible wavelengths, such as in the near-infrared (NIR), are particularly useful for monitoring biophysical variables such as vegetation green-up and soil moisture, while radar and Light Detection and Ranging (LiDAR) data can provide detailed topographic data required to monitor floodplain inundation and vegetation structure.

Box 1. Key applications of Earth Observation to wetland monitoring

Wetland extent and habitat quality

High resolution satellite images (e.g. Landsat, Sentinel 2) and very high resoultion images from manned/unmanned aircraft systems (UAS) allow mapping of wetland extent and areas to varying levels of detail. Multi-spectral images allow detailed mapping of wetland habitat types using unsupervised, supervised and object-based classification (Figure 1). Products such as Normalised Vegetation Classification Index (NDVI) can be derived and used to refine classification and monitor seasonal changes. GIS techniques allow spatial and temporal data to be quantified.

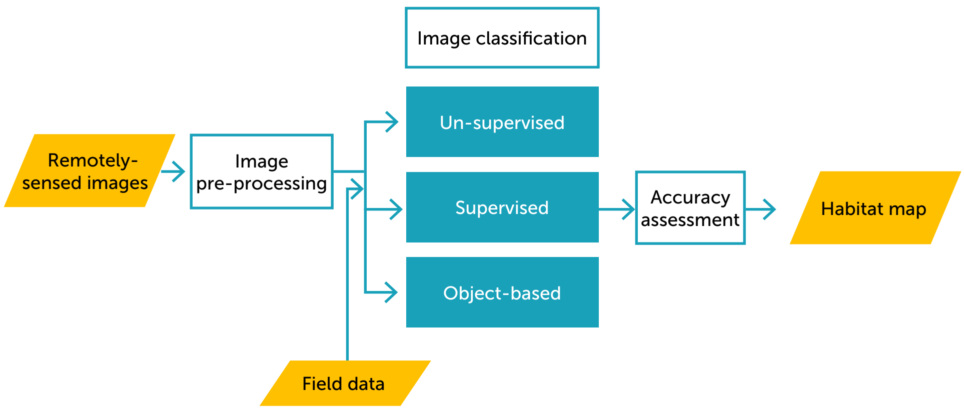


Fig 1. Pathway for deriving a habitat map from remotely-sensed images

Key considerations: Satellite image availability limited by cloud cover and pass frequency of satellite; advanced skills required for detailed wetland classification; field data required to ground-truth analysis; seasonal vegetation changes must be considered during data acquisition; cost depends level of spatial/temporal/spectral resolution required; repeat surveys using manned aircraft could be costly.

Water quality

High resolution multi-spectral imagery used to derive proxies for trophic status and pollution levels from parameters such as chlorophyll-α concentration; suspended matter concentration; dissolved organic matter; cyanobacteria blooms.

Key considerations: Water quality indices mostly developed for water bodies; some processing tools freely available while others require advanced processing skills; costs dependent on EO platform used and availability of open-source data; extensive field calibration required for good results.

Surface-water dynamics and inundation

Many methods available: visual interpretation/digitising and quantifying inundation extent from aerial images; processing of soil moisture/wetness indices from multi-spectral images; monitoring soil moisture changes/inundation below canopy vegetation using Synthetic Aperture Radar (SAR) data; use of LiDAR data to create ultra-high resolution digital elevation models (DEMs) e.g. to assess seasonal water levels.

Key considerations: Skillsets highly dependent on methods used; costs dependent on availability of data for specific site, level of detail required, number of repeat surveys etc.; LiDAR and SAR penetrate cloud.

Resources

A wide variety of free open source global EO datasets e.g. Landsat, Sentinel 2, MODIS, SAR are available to download online from providers such as Sentinel Hub EO Browser, USGS Earth Explorer. Lidar data may be freely available depending on the country, area of interest and use.

Various toolboxes are available for wetland assessment, many of which are open source. For example, ORFEO toolbox is a collection of tools that range from pre-processing of multispectral and radar images, time series creation, extraction of elevation information from stereo images, to segmentation and classification of images. The tools can work through QGIS, Python or through a standalone application (Monteverdi). Most datasets require visualising and processing in a Geographical Information System (GIS) e.g. QGIS 3.16.3, ESRI ArcGIS 10.6. Software requirements are highly dependent on the dataset and level of detail and complexity required in the analysis.

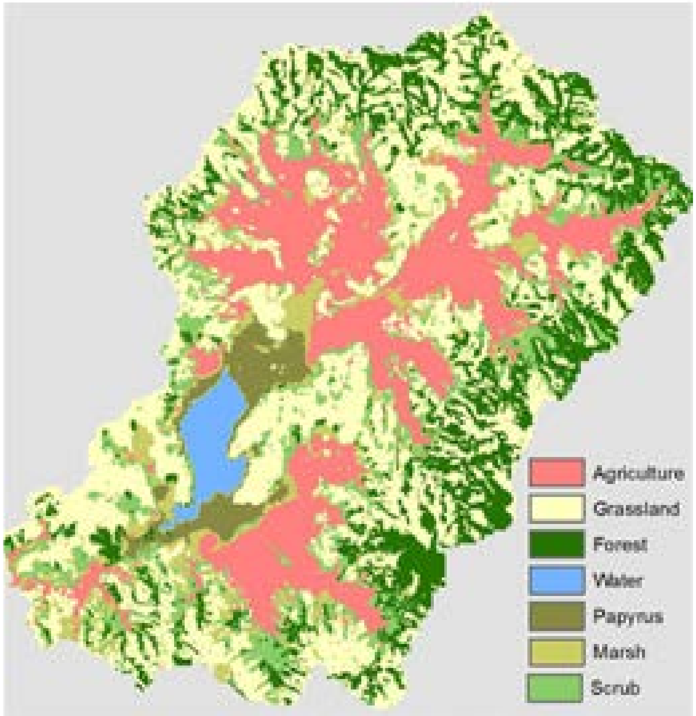


Figure 3.1. An example of a wetland map derived from satellite imagery (Sentinel 2) using object-based classification methods. Lake Sofia in northern Madagascar.

Passive recorders

Fixed position passive recording is a non-invasive monitoring method involving the use of specialised equipment to capture images or sound. The method has multiple applications in wetland sites and as part of a well-designed survey, recording devices can facilitate reliable measurements of biodiversity, ecosystem health and habitat change.

The use of trail cameras (camera traps) and acoustic recording equipment has risen in conservation practice with the evolution of higher-quality, lower-cost equipment. In general, minimal maintenance is required, although data collection can be interrupted through loss of power or reaching the data storage capacity.

(credit): Custom 3D-printed, weatherproof casing for AudioMoth, deployed in the field for acoustic data collection.

Design

Visual and acoustic data can be used for qualitative and quantitative assessments of a given site, providing increased detection sensitivity and lower effort over standard observation methods.

Trail cameras and acoustic recordings are suitable for detecting rare or sparsely distributed species and generating data to describe overall species richness, abundance, and distribution across a specific area.

Visual data can quantify the impact of broad change within habitats, for example after engineered habitat restoration. Deployed over a longer time period, these data can reveal subtle cumulative effects of change. For rapid assessments of wetland health, the acoustic energy in sound recordings can be summarised in simple acoustic indices to compare species richness, for example between bird calls or insect noise. Both sampling methods can provide valuable baseline data to assess change.

Trail cameras have specific applications for assessing threats at a site, such as identifying the presence and abundance of predators, or observing human-wildlife conflict, as well as quantifying target species presence, behaviour and interactions, and determining habitat preferences. Passive acoustic recording devices are valuable for small mammal monitoring, particularly determining bat activity and assessing bird song.

Consideration should be given to the positioning of each recording device depending on the coverage required and number of devices available. For example, where equipment is limited, systematic rotation improves the coverage of a site. When detecting changes over time, standardising the sampling collection is key: fix each device at the same height and direction. In addition, consider the duration of each deployment and account for seasonal effects, such as vegetation height.

Resources

The cost of trail cameras and passive acoustic recorders varies, according to robustness, reliability and sensitivity; however, low-cost equipment can be effective, reliable and can be deployed over a greater area of habitat. In general, fixed position recording equipment is fast and simple to deploy, requiring only intermittent data downloads and battery changes, and various software are now available to support the rapid analysis of data.

Volunteer-led / citizen science

Incorporating volunteers/citizen scientists can add value to your monitoring programme in several ways. Although citizen science monitoring approaches require some initial time investment in training, they typically use simplified approaches that are cheaper and can ultimately be more sustainable longer term, particularly when they engage with stakeholders local to the site. Volunteer led approaches also provide increased opportunity for community engagement, which can lead to an increased awareness of the value of wetlands and the threats they face. There are a range of motivations for getting involved in wetland monitoring as a citizen scientist, it can be useful to understand the motivations of your volunteers and their other commitments so that you can tailor tasks and/or identify volunteer group leaders who can take on some of the training/development tasks longer term. However, long-term support and structure needs to continue to be provided from monitoring programme staff, even if it is at a lower level than is required initially, it needs to be regular to ensure protocol adherence and the maintenance of data quality. It can be useful to carry out more detailed surveys intermittently to ensure trends observed in citizen science data are accurate.

An important consideration when setting up a citizen scientist monitoring programme is health and safety. Carrying out risk assessments and making sure volunteers are aware of the risks and have the necessary sampling/analysis equipment and personal protective equipment (PPE) is vital.

Design

When considering whether to incorporate citizen scientists it is firstly necessary to consider whether a citizen science approach is appropriate. Whilst there are many additional benefits to using citizen scientists, these can be quickly negated by insufficient support and/or management for them. Careful consideration therefore needs to be given to the scale of sampling, the type of data required and the skill level of the potential participants. Training will be necessary not just for the volunteers themselves but also for the staff responsible for managing them. It is important that data management, storage and feedback to the volunteers is considered at an early stage as it can significantly affect the sustainability of your citizen science monitoring programme. Once a citizen science approach has been decided it is important to determine what can be achieved with the resources available. What budget is available It can be useful to establish what already exists in relation to citizen science groups, partner organisations and NGOs and whether there is potential for support for your programme from for example local universities. Longevity of a citizen science monitoring programme will be determined by a number of factors, managing and balancing expectations against the capacity you are able to commit to your volunteers is key. Establishing a system by which your volunteers can provide feedback to you is important. Similarly providing regular feedback and updates to your citizen scientists and setting the context for their contribution (i.e. providing the wider picture of where their work fits in) is vital.

4. Data management

General management

Good data management is fundamental to the effective running of monitoring programmes. Planning ahead and employing good data management practices will increase the efficiency of your monitoring programme and help ensure:

- You have adequate resources in place;
- You meet legal and ethical requirements;
- Your data are of good quality and are accurate and reliable;
- Your data are secure and you can avoid or minimise data loss;
- You meet the requirements of e.g. funders, project partners, institutions; and
- Your data are accessible and re-useable.

The process of data management is applied throughout the life cycle of the data, from collection to use and archiving. It involves a range of activities from simple administrative tasks (e.g. filing data) to the more technical aspects (e.g. database maintenance).

The level of data management needed will vary between monitoring programmes and is influenced by e.g. the quantity of data being collected, the resources available (including budget and people) and the longevity of the programme.

A useful tool to have in place is a data management plan that describes how you treat your data and sets out the protocols and policies that you will apply throughout its life cycle.

When planning your data management:

- Identify what data you will be collating: such as, data type and format (e.g. spreadsheets, text, images, audio files, geospatial data), the volume of data, and the data source (e.g. visual observations, field equipment, questionnaires).
- Decide what data capture system you will need based on the above: e.g. small amounts of data tables can be managed in spreadsheet programmes; large volumes of data may require a relational database management system; and geospatial data will require a Geographic Information System (GIS). Consider using open source programmes if your budget is limited.
- Define a suitable filing system to capture your data at the different stages including the raw data (direct from the source), the validated and analysed data and the data products.
- Consider how you will document your data i.e. the associated metadata: such as, details of what, where, when why and how the data were collected, processed and analysed, and a description of how data and files are named, structured and stored.
- Describe your data assurance procedures: such as, validation and verification measures to assess and improve data quality, and version control. These procedures can include manual and/or automated processes.
- Define how your data will be stored and preserved: such as, data storage (e.g. local computer or server), back-up systems and data security measures.
- Specify your data policies and consider any legal requirements: such as, licensing and sharing agreements, and legal and ethical restrictions on accessing personal or sensitive data.

- Determine - before you start gathering data – how you will analyse and interpret it. This is a critical step in the planning stage; if you leave these decisions until it is time to report, you may find that your data are not suitable for the analysis that you would like to do. Data analysis is a specialist skill, so it is important to decide who will do this, and involve them at an early stage.
- Determine how your data will be disseminated: e.g. what, when and how will your data and data products be made available. Consider if you need to cater to any differing requirements of e.g. your funders and project partners.
- Set out roles and responsibilities for all those involved in any part of the data handling and processing: such as, data collection, data entry, data archiving, administration, database maintenance, analysis and reporting. Consider if any training of personnel will be required to carry out these tasks.

Always consider the resources you have available and only initially set up what you really need. Data management can and will evolve as your monitoring programme develops; hence, it is advisable to regularly review data management throughout the lifespan of your programme to ensure it continues to be fit for purpose.

There are now some very good software applications that enable monitoring data to be entered into customised systems on smartphones and/or tablet computers in the field. These can help the process by automating the process of moving the data from field records to database. An example is the SMART (Spatial Monitoring and Reporting Tool https://smartconservationtools.org/) system, but there are others worth considering.

GIS data management

Data management should be carefully considered where geospatial data is collected within a monitoring programme. The level of data management is dependent on the volume and complexity of the data, processing requirements and the number of people who will have access/editing rights. Computing performance is also an important consideration at the outset of a project.

File management and version control is essential, as GIS processing often involves the creation of many intermediate files before ending up with the final polished dataset. Consider using separate workspaces for input data, intermediate workings, final outputs and GIS projects, and ensure there is a strong file-naming system in place. When sharing GIS projects and data between users, the project file (e.g. .MXD, .QGIS) and associated data should be stored in the same directory to allow data to be read into the project.

It is important to maintain clear and accurate metadata to document the data, including information such as content, origin, date, author, spatial reference system, details of processing/analysis, description of fields. Many geospatial file formats allow metadata to be directly associated with the data.

Vector data (points, lines and polygons) are commonly stored as ESRI shapefiles, which are made up of at least three separate files .SHP, .SHX and .DBF. For GIS software to read a shapefile, all files should all be stored in the same file path –important to remember when sharing and disseminating with other users.

Browsers such as ArcCatalog and QGIS Browser are helpful in organising and managing GIS datasets, allowing files to be moved, renamed, previewed, and metadata viewed, which cannot be achieved in Windows Explorer.

For projects with substantial geospatial data components e.g. those involving satellite image storage and processing, consider using a geodatabase to store multiple attribute tables, vector and raster datasets as well as relational information, raster mosaics, scripts and processes.

Geodatabases allow processes to be automated easily, leading to faster processing and standardisation, useful for repeated monitoring events. Databases can also be compressed, and allow multiple users to view data while the geodatabase is being edited by another user. Some commonly used geodatabases include GeoPackage, SpatiaLite, PostGIS, (all open source) and the ESRI File Geodatabase.

Projects involving heavy collaboration between multiple users are increasingly using cloud-based GIS. Cloud-based software can open up monitoring to citizen scientists, and can be integrated with real-time data collection e.g. via smart-phone apps, increasing the engagement aspects of a project. Maps and data can be published and shared easily between organisations or individuals, which reduces the need for costly GIS server software.

Summary

By following the design steps recommended in this guide, your site should now have a strong monitoring programme suited to your Ramsar Site and appropriate to the level of available resources. Once implemented it will allow the effectiveness of site management activities and protection measures to be evaluated, and adapted if necessary. Ultimately this is expected to lead to improvements in site features, particularly those on which your Ramsar Site designation is based.

5. CASE STUDIES

Case Study 1: Methodology used to monitor Odonata at Mai Po Nature Reserve, Hong Kong S.A.R., P.R. China.

The Mai Po Nature Reserve in Hong Kong, managed by WWF-Hong Kong, supports a series of rain-fed ponds and marshes, converted from former commercial fishponds. In 2003, two volunteers surveyed adult Odonata on these rain-fed habitats to identify the species present, their relative abundance and diversity. The survey became a regular activity from 2006 onwards and is now an established component within the wetland's monitoring plan. A second activity to monitor breeding Odonata also started in 2006.

The main objective of both monitoring activities is to provide relative abundance and diversity data for adult and breeding Odonata, to inform habitat management decisions on the rain-fed habitats. The data also serves to assess related indicators in the management plan.

Monitoring flying adults

A survey involves walking a 2.68km transect route along pond edges and sections of boardwalk, through approximately half the rain-fed habitat. Surveys are conducted at a slow pace and not allowed to exceed 2.5 hours with equal 'effort' upon each pond applied.

All odonate adults within 3m on the specified side of the transect are recorded for each section along the transect route. Care is needed to avoid double-counting of individuals moving during the course of the survey.

Surveys start in mid-March and finish in mid-October. A survey is conducted approximately every 2 weeks, alternating between a morning count (between 10:00 and 13:00) and an afternoon count (between 15:00 and 18:00). The direction of the transect route is reversed each time. To save resources, data sets are collected twice in every five-year period.

Essential survey equipment includes a pair of binoculars (8x magnification or above), a voice recorder or recording form, and a watch. Optional equipment (depending on the surveyors' skills) includes an Odonata field guide, a hand tally counter, pencil/pen and paper, and a camera.

Odonate exuviae

Each survey involves the collection of exuviae from 40 randomly placed emergence traps set along pond edges in 5 different rain-fed ponds included in the adult flying transect route. The emergence traps followed recommended guidance, i.e. their total surface area being approximately 14.4m²/pond and no less than 8 traps per pond. The traps comprised a nylon screen mesh (L x W x H : 56cm x 37cm x 29cm) in an aluminum wire box set on the edge of a pond staked with a bamboo cane (Photo 1). Each trap had a waterproof label containing a brief description of the purpose of the equipment and telephone contact number of the WWF office.

The traps were set in mid-March and collected back at the end of September. The traps were set in such a way that emerged adult Odonata could escape and positioned above the waterline. They had to be regularly adjusted if water levels fluctuated in the ponds, or if nearby vegetation growth was obstructing the data collection.

A survey involved the collection of exuviae attached to each screen at the end of each month. Exuviae were placed in vials and identified to species level back in the laboratory. However, if heavy rain was forecast, an extra collection was arranged otherwise exuviae might be washed off the traps.

Similar to the adult flying monitoring, two complete data sets were completed within every five-year period.

Long-term monitoring has identified the more important ponds for Odonata, and those in need of management or enhancement such as vegetation control or water quality improvements, to increase their value to Odonata. An example data set from 2009 is shown in Figures 1 and Figure 2.

The exuviae data revealed over 90% of Odonata had emerged by the end of July. This provided justification for a very short duration drawdown of a handful of ponds in August to carry out predatory fish removal with minimal impact on Odonata.

Mai Po Nature Reserve

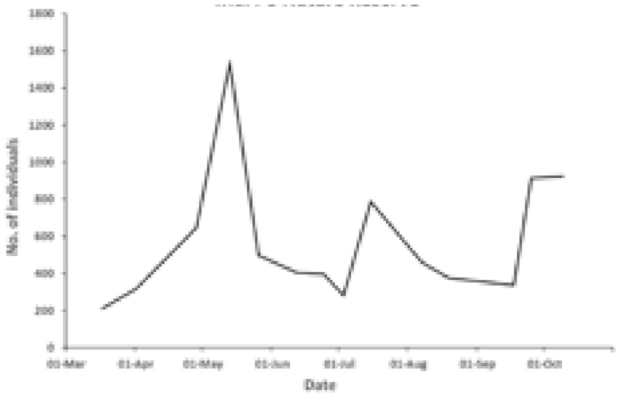


Figure 5.1. Adult odonata data in 2009.

Mai Po Nature Reserve

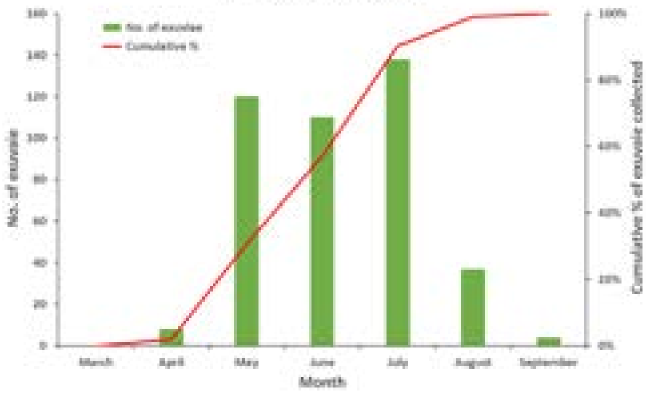


Figure 5.2. Exuviae count data in 2009.

© Graham Reels

(Image caption) An exuviae trap at one of the monitored ponds.

Case Study 2: Design of a groundwater monitoring network at Boeung Prek Lapouv Protected Landscape, Cambodia

In 2020, the Wildfowl and Wetlands Trust (WWT) set up a network of groundwater monitoring points in the 8,305 ha Boeung Prek Lapouv Protected Landscape (candidate Ramsar Site) in Southern Cambodia. The site is one of the last remnants of seasonally inundated grasslands in the Lower Mekong Delta used by a rapidly declining population of sarus crane *Grus antigone*. Through rice farming and the provision of wetland resources, the site supports the livelihoods of 12,000 people.

There is concern the site is gradually drying out in part due to changing precipitation patterns driven by climate change, but also attributed to modifications in the Mekong River flow caused by upstream hydroelectric dams and increasing water-intensive rice production.

Long-term surface waterlevel data collected at the site supports this concern, however change in subsurface waterlevels is not known and could potentially be negatively affecting species and habitats, such as the grass-like sedge *Eleocharis dulcis* (an important food for sarus crane) which requires high groundwater in the non-flood or dry season. Groundwater data is also needed to evaluate future efforts to restore grassland.

To minimise costs, conventional 2m long dipwell tubes were chosen as the main in situ equipment. These are easily made from PVC materials available in hardware stores, are simple devices to collect data from and provide good quality reliable data if maintained well.

As a general rule, the number of groundwater monitoring points to be installed in a wetland is determined by the complexity of the hydrology (e.g. the number of drains or channels), the monitoring objectives and the area of the wetland. For Boeung Prek Lapouv, we collated useful guidance from different publications and previous experience of using dipwell tubes at our sites. Monitoring points should:

- Represent the main ecosystems and main soil types;
- Be located away from roads and human settlements;
- Represent the different elevations of the wetland;
- If possible, located away from wildlife sensitive areas to minimise disturbance when data is collected;
- Provide a good spatial coverage;
- Avoid locations where there is a risk of damage from agricultural machinery; and
- At the site, be located close to the existing surface water gauge boards and water quality monitoring points, to aid data interpretation.

To ensure that both the communities and local authorities supported the installation of groundwater monitoring equipment and data collection, WWT organised a series of introductory sessions for them. We also avoided locations that might have led to disagreement or potential conflict with the communities.

This enabled a site-wide monitoring network to be designed. In consideration of limited financial and human resources, 20 locations were prioritised, Figure 1, and installed, Photo 1. Additional monitoring points may be added in future should groundwater flow direction need to be determined.

Members of the local Field Monitoring Team were trained to collect and record the data. Readings are taken weekly, usually 7 days apart, at any time of the day. Data collection starts as soon as the flood waters recede in January and finishes when the flood season commences in early September or the wetland is flooded. The elevation of each dipwell tube was determined so levels can be referenced against the general topography, existing habitats and surface water gauge boards.

Data from the first dry season (Figure 2) encountered a few problems, mostly logistical, but the monitoring team overcame these and the data quality improved as confidence grew in collecting the data.

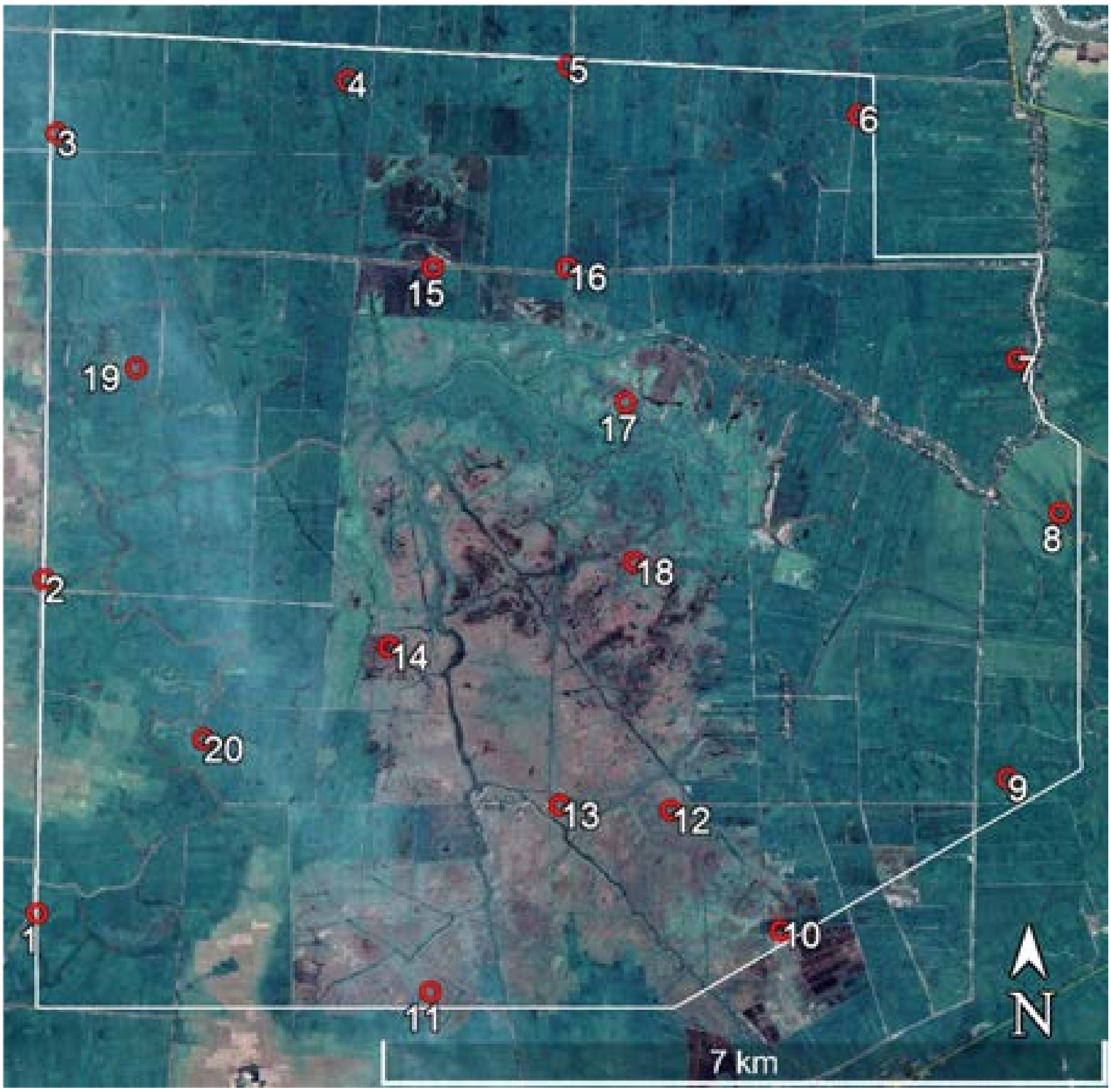
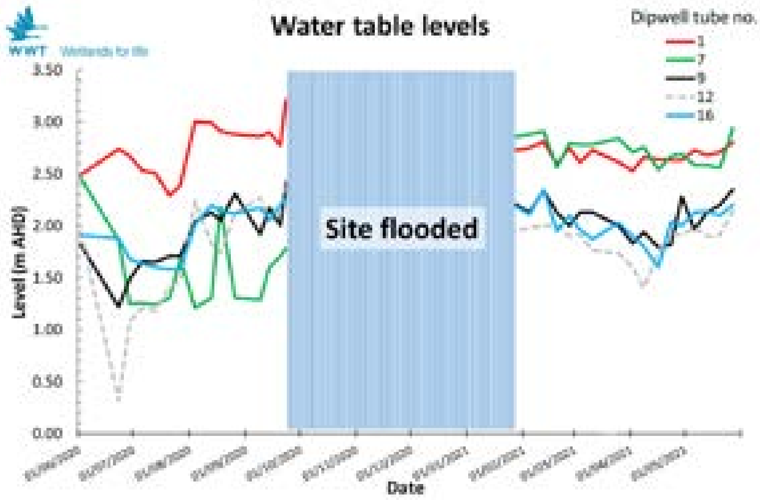


Figure 5.3. Location of groundwater monitoring points inside Boeung Prek Lapouv Protected Landscape (Base map from Google Earth 2021).

continued...



above: (caption) Measuring the groundwater level at a dipwell tube. The brick casing and lockable lid are used to prevent people tampering with the equipment or being damage by livestock

Left: Figure 5.4. Example data collected from the first dry season.

Case Study 3: A comprehensive water quality monitoring programme in Changshu Wetland City, P.R. China.

Changshu is located in the middle and lower reaches of the Yangtze River and the lower reaches of Taihu Lake. Changshu was designated as a Wetland City of the Ramsar Convention in 2018. Its geographical location plays an important role in the protection and construction of the wetland network in the region, as well as the protection and improvement of the water quality in the Yangtze River and Taihu Lake. In 2017, the first county-level wetland monitoring centre, Changshu Wetland Monitoring Centre, was established, along with a city-wide wetland ecological monitoring network. A detailed programme of field investigation and monitoring of important wetland areas in Changshu was carried out. The aim was to comprehensively analyse the current situation and monitor changes, and to provide a scientific basis to make decisions and plan the city's wetland protection and management.

Based on water characteristics and site condition, ten important wetland sites in the city were selected for water quality monitoring: Shajiabang National Wetland Park, Nanhu Provincial Wetland Park, Nicangxiao Provincial Wetland Park, Changshu Section of the Yangtze River, Shanghu Lake, Kuncheng Lake, Taodang, Guantang, Liulitang and Chenhaiwei. Using the national "Surface Water Environmental Quality Standard" (GB3838-2002) and an understanding of the local pollutants in Changshu's wetlands, a set of water quality indicators were selected. These included pH, water temperature, dissolved oxygen, conductivity, transparency, chlorophyll, total nitrogen, ammonia nitrogen, total phosphorus, chemical oxygen demand (COD), five-day biochemical oxygen demand (BOD5), suspended solids, volatile suspended solids and microorganisms.

Thirty-four outdoor wetland ecological monitoring devices were installed in the 10 wetlands to monitor their water and air quality and meteorological variables. Thanks to the development of an intelligent cloud monitoring and management system, the data can be tracked online on the “Changshu Wetland Ecological Monitoring Centre Monitoring and Management Platform” allowing the state of each wetland’s environment to be assessed in real time.

Water quality monitoring in Changshu is carried out monthly by four appropriately trained staff knowledgeable in the standards and specifications relevant to sample collection, sample storage, sample testing, and data analysis and evaluation. This ensures the accuracy and reliability of the results.

Analysis of the collected data reveals stark differences in the quality of water in the 10 wetlands with best quality in Shanghu and Nanhu wetlands. Here, the concentration of pollutants is low enough to meet the standards of Class III water quality in China. Liulitang wetland has the poorest water quality with a particularly high total nitrogen concentration due to industrial and domestic sewage in the surrounding areas, meaning it is classified as Class V water.

This understanding of the status of wetlands in Changshu, through the analysis of water quality monitoring data, provides a scientific basis for the government to make informed decisions for the betterment of effective protection and comprehensive management of water resources in the area.

A case in point is data from Kuncheng Lake, which showed total phosphorus as the main pollutant. As a result, the local management department actively carried out a number of water purification projects to reduce pollutants in rivers flowing into the lake. These measures proved effective and reduced the total phosphorus content in the Lake.

Changshu has demonstrated that a long-term, well-designed water quality monitoring programme which provides accurate reliable data provides a strong scientific basis for the protection and management of wetland resources.

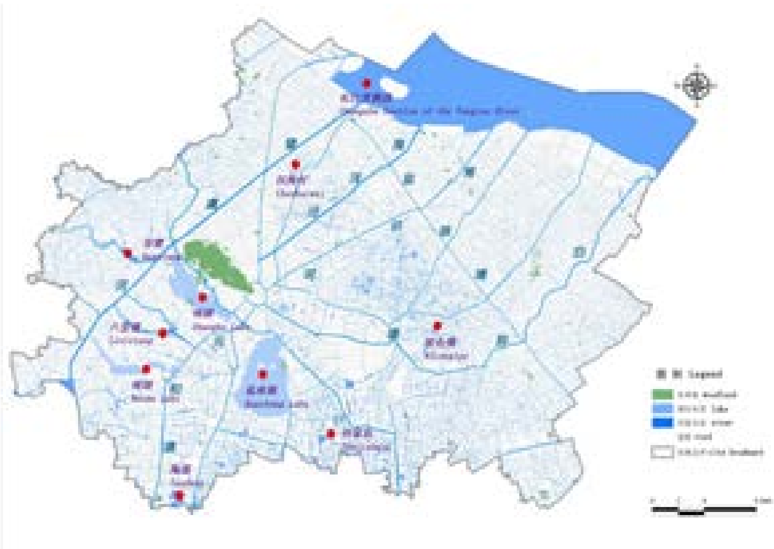


Figure 5.5. Ten water quality monitoring stations in Changshu.

(caption) Water sampling in the Kuncheng Lake.

Case Study 4: Waterbird abundance response to habitat improvements at Chongming Dongtan National Nature Reserve, P.R. China

Chongming Dongtan National Nature Reserve (NNR) and Ramsar Site is a 32,600 ha coastal wetland mainly comprising estuarine waters and intertidal mud, sand and salt flats. It is one of the most important coastal sites for migratory waterbirds in the Yellow Sea, and the protection of these birds is a high priority objective for the reserve.

The numbers and diversity of these waterbirds are indicators of environmental change and are related to the condition of habitats at the wetland. Therefore, waterbird counts are regularly conducted. Each spring and autumn, some waterbirds are also fitted with leg flags/bands to study their movements and understand which habitats they use.

Counts are conducted monthly with an extra survey in spring months (March, April, May), and autumn months (August, September, and October). Counts on the inter-tidal mudflat are divided into 3 areas, each requiring 2 to 3 surveyors. The surveyors are positioned along three north to south line transects set according to the vegetation-mudflat ecotones within the core zone of the reserve. Other counts take place within various man-made wetlands in and around the NNR including the SIIC Wetland Park, the Beibayao Experimental Area and the Ecological Restoration Area of the Reserve. Four groups of surveyors conduct coordinated counts in this area (Figure 1).

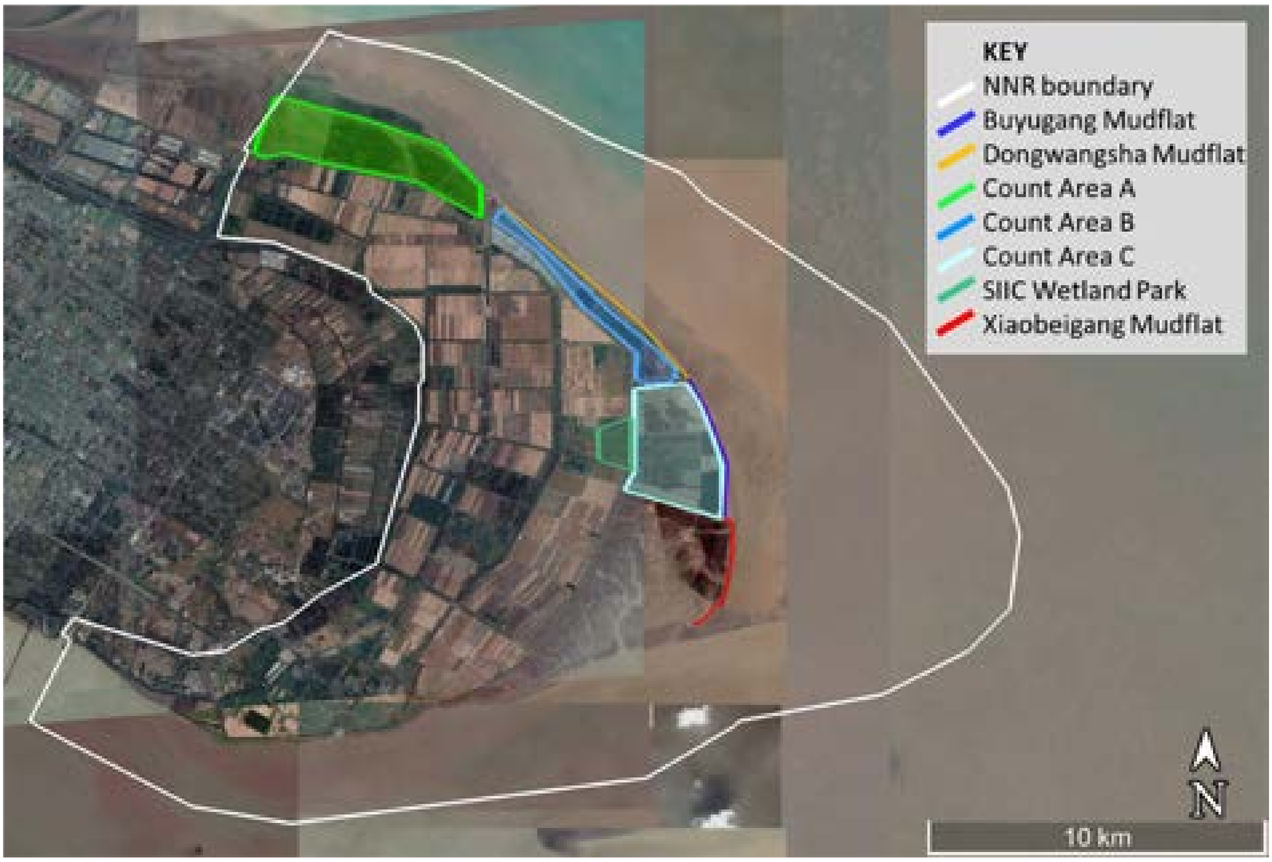


Figure 5.6. Waterbird count areas within Chongming Dongtan NNR (Base map from Google Earth 2021).

Each survey team member arrives at the designated survey location by car or on foot, and conducts a count using a high-powered telescope and minimum 10 times magnification binocular. Typically, one person observes and counts the waterbird to species level, whilst the other person records the data. Additional equipment includes a digital camera and a GPS.

In 2006, 112,066 waterbirds (87 species) were recorded in the NNR, but this declined to a low of 39,734 waterbirds (81 species) by 2009, Figure 2. The main reason for the decline is land-use change in the outer buffer zone and the spread of the invasive non-native Spartina alterniflora, which reduced the area of suitable waterbird habitat.

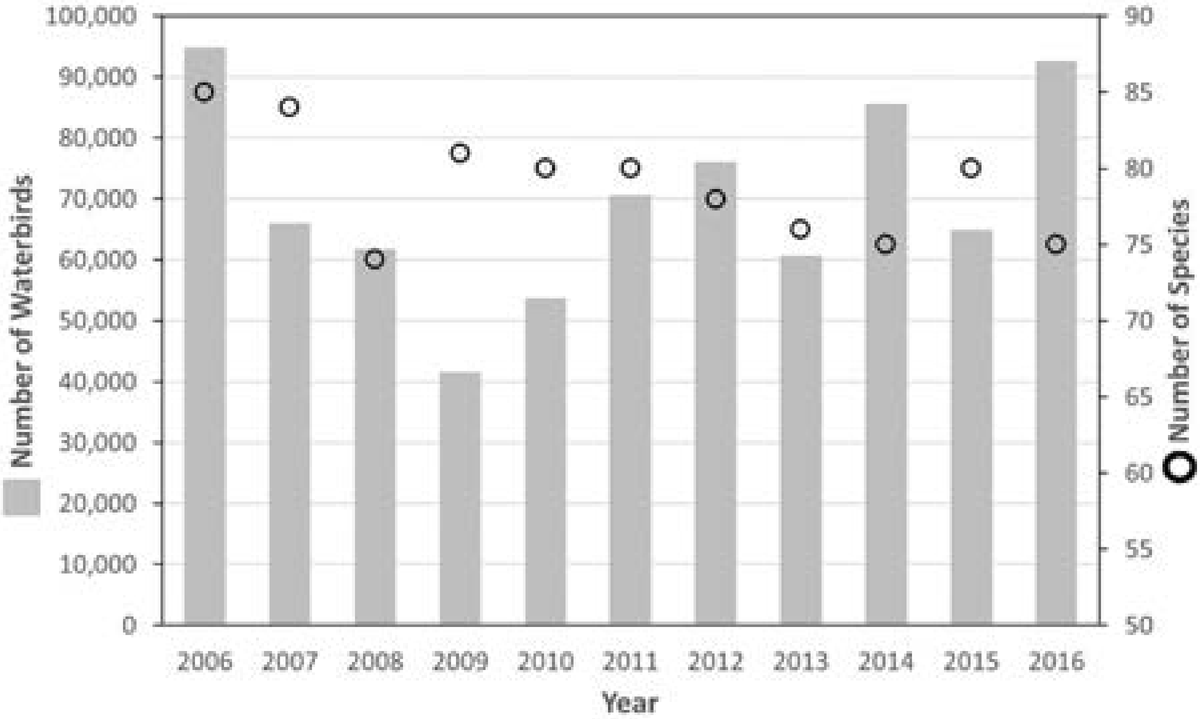


Figure 5.7. Changes in the number of waterbirds and species in Chongming Dongtan NNR from 2006 to 2017.

In response to the significant decline in the number of waterbirds, in 2013 the reserve initiated an ecological restoration plan to clear the *S. alterniflora*, and create semi-natural wetland habitats for waterbirds, Figure 3. Through sensitive engineering and ecological considerations, 24.2 square kilometres of wetland habitat was restored or constructed, 25,367 acres of *S. alterniflora* was removed, 2,000 acres of *Scirpus mariqueter* were planted, and 56 islands with habitat features for waterbirds were created. The control rate of *S. alterniflora* was over 95%.

As shown in Figure 2, 58,697 waterbirds (76 species) were recorded in 2013 at the start of the ecological restoration project. By 2017, the number had reached 100,541 (79 species). As such, the restoration reversed the declining trend, however the diversity of waterbirds species remained fairly constant.

In 2020, 194,484 waterbirds (82 species) were recorded, a significant increase. Twenty-three species are classified as nationally rare protected birds, including tundra swan, black-faced spoonbill, oriental white stork, and white-head crane, have been recorded in the ecological restoration area.

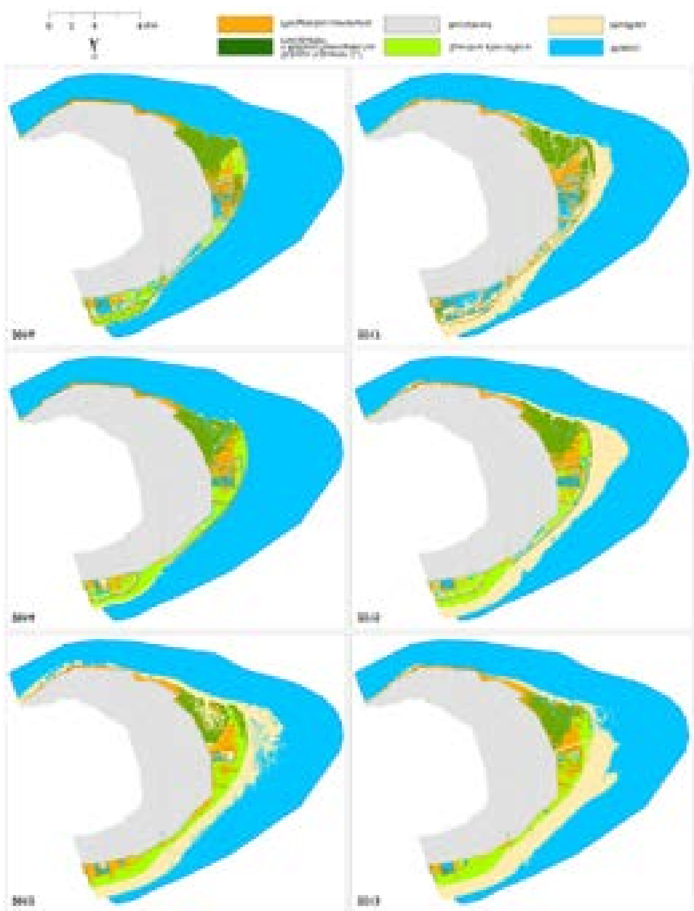


Figure 5.8. Dynamic changes of key plant communities from 2012 to 2017 in the Chongming Dongtan NNR.

Case Study 5: Mangrove dieback area monitoring and restoration Sydney Olympic Park, Australia

Following detection of an area of mangrove dieback of approximately 7,000m^2 in a 190,000m^2 area of mangrove (Grey Mangrove, *Avicennia marina*) in Sydney Olympic Park, Australia, a scientific investigation was conducted to identify the root cause/s of the dieback (Figure 1). The investigation involved visual assessments and gathering of field data in many parameters to ascertain the cause/s of the dieback.

The scientific investigation required that it was able to satisfy the needs to draw logical conclusions on the cause/s of the dieback. It also required that the same method of the investigation could be applied to detect if any restoration measures helped improving the area. Most aspects of the investigation are referred to as 'monitoring' in this case study. It was important that monitoring was undertaken as a regular practice even when no problems existed but it helped detecting problems and ascertaining if rectification to the problem was effective or not.

To draw scientific conclusions, ideally, statistical hypotheses were drawn and those were tested by conducting the monitoring.

The data collection required allowing replicate sites to satisfy the requirement of a proper statistical analysis. Although this required addition resources such as staff time, ample replications were necessary to minimise variations in the results due to other factors. In this case, 3 to 5 replicate sites were selected for each parameter that were monitored in each type of habitat. The frequency of the data gathering varied depending on the parameters that were monitored because not all parameters required the same narrow time interval between consecutive events of data collections. The data intervals were primarily before the dieback occurred, after the dieback itself but prior to the restoration, and after the restoration. Of course, the monitoring required the right skills and time but in this case, a combination of experienced personnel and graduating university students were involved in the data collection.

The first set of data was the hydrological investigation. The second set of data was the various ecological parameters. These included mangrove tree count, seedling count, aerial root count, gastropod mollusc count, crab holes count and canopy gap data. The third set was sediment and water chemistry, which included sediment salinity and pH; water salinity, pH, dissolved oxygen and temperature.

Various types of data offered information on respective aspects of the problem in the dieback area. The hydrological investigation confirmed that the dieback area had water-logging compared to the nearby area. Visual observations confirmed that the water-logging was due to clogging of the drainage channel and it was from a combination of mangrove root growth and sediment deposition in the channel. Ecological data confirmed dead mangroves, decomposed aerial roots, dead seedlings, absence of crab holes, deteriorated sediment and water qualities. Ultimately, the area turned into a decomposing, putrid and unhealthy system. Some of the data are shown in Figure 2.

After analysing the above data and results there were two aspects that were very clear. One, due to the clogging of the channel, the incoming tide either could not reach the mangrove dieback area and only larger tides were able to overtop the clogged barrier but could not drain out. Two, rainwater could not drain out of the water-logged area. These two conditions have caused the mangrove dieback and the ecological parameters such as tree count, seedling count, aerial root count, gastropod mollusc count, crab holes count – all of these have shown significantly inferior counts than before. Therefore, to resolve the problem only two possible solutions were available. Firstly, to remove the barrier (clogging) to the water drainage; and secondly, to construct a bypass channel that could facilitate adequate tidal exchange and augment full drainage of the dieback area. After careful consideration of various environmental factors, logistics and cost implications, it was decided that a bypass channel was the most sensible approach. In choosing the option, likely influences of sea level rise and climate change were also taken into account so that these were unlikely to confound the problem in the future and compromise the restoration attempt. At the same time, some of the clogged area was also cleared by removing sediment and mangrove roots.

After carefully conducting hydrological calculations, the size, dimension, location and elevation of the bypass channel was designed and constructed. Post-construction monitoring was conducted of the same parameters as pre-restoration. To maintain consistency, the same monitoring methods, as before, were repeated.

Data have clearly shown that the dieback area no longer had water-logging, confirming that the constructed channel had effectively drained the previously water-logged area. It was also clear from the ecological parameters that new seedlings were colonising; aerial roots were settling in; half-dead trees, that did not completely die, started regrowing; the sediment and water qualities improved and the overall health of the area improved. Some of these data are presented in Figure 2.

above: dieback condition and volunteers undertaking monitoring works

left: mangrove regrowth in the dieback area after the restoration

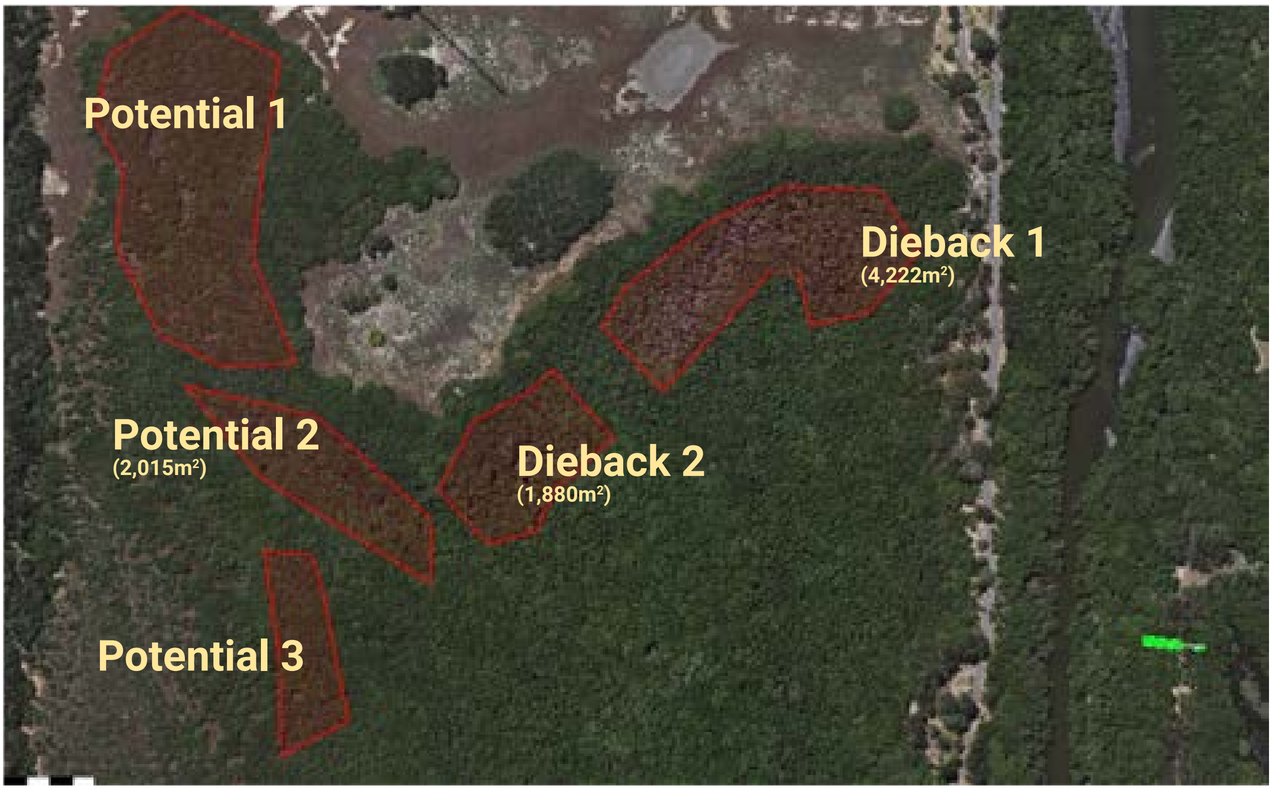


Figure 5.9. Mangrove dieback site in Badu Mangroves (photo 2014). (Dieback 1 & 2 are dead patches and Potential 1-3 are the patches that were likely to be dead if restoration works were not undertaken).

Figure 5.10. Confirming that the constructd channel had effectively drained the previously waterlogged area.

APPENDIX - Further reading

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Ramsar Site Information Sheet https://www.ramsar.org/document/resolution-xi8-annex-1-ramsar-site-information-sheet-ris-2012-revision

Sutherland, WJ (ed) (2006). Ecological Census Techniques. 2nd Edition. Cambridge University Press.

BirdLife International's Important Bird Area (IBA) network is one of the largest global key site networks. BirdLife has developed simple guidance for IBA monitoring, especially relevant to sites where capacity is limited. See: http://datazone.birdlife.org/userfiles/file/IBAs/MonitoringPDFs/IBA_Monitoring_Framework.pdf

Key Biodiversity Areas (http://www.keybiodiversityareas.org/) is a programme involving most of the large global conservation organisations, which aims to identify and conserve the world's most important biodiversity sites. http://www.keybiodiversityareas.org/working-with-kbas/publications provides some useful references to site-based monitoring methods.

Foundations of Success (https://fosonline.org/) is an organisation that aims to help practitioners to improve the practice of conservation. The website provides many useful resources that help to plan and manage protected areas, and specifically manuals to support monitoring. See:

- Rao, M., E. Stokes and A. Johnson. 2009. Monitoring for Management of Protected Areas – An Overview. Training Module 6 for the Network of Conservation Educators and Practitioners. American Museum of Natural History and the Wildlife Conservation Society, Vientiane, Lao PDR. https://fosonline.org/library/monitoring-for-mgmt-of-protected-areas/.
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Lampert, W. and Sommer, U., 2007. Limnoecology: the ecology of lakes and streams. Oxford university press.

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Wetzel, R.G., 2001. Limnology: lake and river ecosystems. Gulf professional publishing.

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Shaw, E.M., Beven, K.J., Chappell, N.A. and Lamb, R., 2010. Hydrology in practice. CRC press.

Gordon, N.D., McMahon, T.A., Finlayson, B.L., Gippel, C.J. and Nathan, R.J., 2004. Stream hydrology: an introduction for ecologists. John Wiley and Sons.

Sprecher, S.W., 1993. Installing monitoring wells/piezometers in wetlands. ARMY ENGINEER WATERWAYS EXPERIMENT STATION VICKSBURG MS. https://wsdot.wa.gov/sites/default/files/2017/07/24/Env-Wet-InstallMonWellsPiezometers.pdf

Harvesting, hunting, bycatch

Ramsar CEPA (communication, capacity building, education, participation and awareness) https://www.ramsar.org/activity/wetlands-cepa-methods

Human disturbance

Mengak, L., A.A. Dayer, R. Longenecker, and C.S. Spiegel. 2019. Guidance and Best Practices for Evaluating and Managing Human Disturbances to Migrating Shorebirds on Coastal Lands in the Northeastern United States. U.S. Fish and Wildlife Service. https://www.atlanticflywayshorebirds.org/documents/Guidance_BMP_evaluating_managing_human_disturbance_final_full.pdf

Ecological processes

Environment Agency (2003). A guide to monitoring water levels and flows at wetland sites. Environment Agency, Bristol, UK. https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/290440/scho0703bfoi-e-e.pdf

Biota

The 'Techniques in Ecology and Conservation' series, published by Oxford University Press contains some incredibly useful books. The following are particularly relevant:

Amphibian Ecology and Conservation

Bird Ecology and Conservation

Freshwater Ecology and Conservation

Marine Mammal Ecology and Conservation

Remote Sensing for Ecology and Conservation

Reptile Ecology and Conservation

Insect Conservation: a handbook of methods and approaches

New Zealand Department of Conservation gives excellent guidance on some biota monitoring methods

https://www.doc.govt.nz/our-work/biodiversity-inventory-and-monitoring/birds/

https://www.doc.govt.nz/our-work/biodiversity-inventory-and-monitoring/freshwater-fish/

https://www.doc.govt.nz/our-work/biodiversity-inventory-and-monitoring/freshwater-ecology/

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Anderson JT, Zilli FL, Montalto L, Marchese MR, McKinney M, Park Y-L (2013). Sampling and processing aquatic and terrestrial invertebrates in wetlands. In JT Anderson and CA Davis (eds). Wetland Techniques, volume 2: Invertebrates. Springer, Dortrecht.

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Ecosystem services

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RRC-EA.2020. Rapid Assessment of Wetland Ecosystem Services: A Practitioners' Guide. Ramsar Regional Center – East Asia, Suncheon, Republic of Korea. http://rrcea.org/rawes-practitioners-guide/

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Fitak E & Keramitsoglou I 2008 (Editors). Inventory, assessment and monitoring of Mediterranean Wetlands: Mapping wetlands using Earth Observation techniques. EKBY & NOA. MedWet publication. (Scientific reviewer Nick J Riddiford).

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USGS Earth Explorer https://earthexplorer.usgs.gov

ORFEO toolbox https://www.orfeo-toolbox.org

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