

CITIZEN SCIENCE FOR
ECOLOGICAL MONITORING
IN WESTERN AUSTRALIA



CONSERVATION
COUNCIL
OF WESTERN AUSTRALIA INC.

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FOREWORD

Western Australia is home to some of the most unique plants and animals on Earth.

From the spectacular rugged red coastline of the Kimberley to the majestic forests in the south west, our special places are a fundamental part of what it is to be a Western Australian.

For over forty-thousand years, Aboriginal people relied on close observation and a deep understanding of ecosystems to provide for their every need. Over this time, the environment slowly changed in response to climatic changes, and human impacts such as hunting and fire.

In the last 200 years the rate of change has dramatically accelerated, with the clearing of the wheatbelt, urban expansion, industrial pollution, weeds, feral animals, and the recent mining boom.

Adding to these pressures, we are also facing a global climate change emergency which is projected to have dramatic impacts on our highly adapted species and ecosystems.

One of the greatest challenges we face in managing and protecting our unique ecology is the lack of understanding of how our ecosystems operate and how they are responding to human pressures.

Investment in comprehensive research and ecological monitoring has not been a priority of governments and as a result, in many cases the best information we have to work with has been collected and recorded by volunteer members of the community.

At the Conservation Council, we aim to inspire and engage people to help protect and look after our special places. Being part of a Citizen Science project is one of the most powerful ways that you can contribute to a more sustainable future for our incredible biodiversity.

This Citizen Science handbook provides a toolkit for communities to engage and co-ordinate their efforts in building a better picture of our unique ecology and a greater awareness of the need for its protection.

Piers Verstegen

Director, Conservation Council of WA





PREFACE

Citizen science is the term used to describe the many highly skilled, although often unpaid, natural scientists in our community. There exists a variety of manuals on ecological monitoring techniques that describe and advocate the use of bioindicators that may be employed by citizen scientists. However most fail to provide the strategic or management context and basic scientific design that is necessary to plan and implement an effective citizen science program.

The *Citizen Science for Ecological Monitoring* handbook is in two parts. Part A introduces citizen science and the concepts behind monitoring design and sampling, with a focus on the use of bioindicators. Part A also deals with the necessity of designing monitoring programs to address an objective, which may have to be discovered or formulated. The aim at the conclusion of this section is to provide a template for citizen scientists to design, plan and implement an effective monitoring program.

In Part B, this monitoring template has been applied to four demonstration projects that were developed through the planning and pilot stages as part of this project. Over 50 citizen-scientists, experts and interested lay-people alike, assisted in the field work that road-tested various methodologies.

INTRODUCTION TO CITIZEN SCIENCE

What is citizen science?

Citizen science is research or monitoring conducted by individuals or communities in the interest of the general public. As it is not directed by government or driven by commercial objectives, participants are usually wholly or partly unpaid, although this may not always be the case. For example a community may decide to raise funds independently for a project.

Citizen science focuses on research and monitoring programs that governments or businesses can't or won't do, perhaps for budgetary, legally defensive or political reasons, but are nevertheless of relevance to local communities or public interest groups. Governments are often averse to resourcing labour intensive and open ended activities such as long-term ecological monitoring. Yet activities of this kind are essential in understanding the actual biological responses to a change in the environment, for example changes as a result of climate change, or to assess the long-term outcomes of biodiversity oriented natural resource management practices and projects. The Conservation Council of WA's (CCWA) Citizen Science Program is designed to build capacity at the community level and to fill some of the important gaps in knowledge left by our governments, industries and research institutions.

Is it science?

Scientific investigation is characterised by the systematic reporting of structured, repeatable observations subject to expert peer review. Science is defined by what it is and not by who does it.

Research institutions of government and the private sector have the specialised resources and expertise to do many things that are beyond the direct reach of citizen science. However, their research directions are largely limited and controlled by the short – cycle funding priorities of governments and corporations. Long-term tasks such as ecological monitoring are not activities that normally fall within the scope of research programs likely to attract funding to scientific institutions.

Academics, in particular, do not look upon monitoring activities as science, principally because such investigations are unlikely to produce major advances in scientific theory. This view is perhaps highlighted by the absence of long-term data-sets or time series, particularly in an Australian context. It is also argued that monitoring is not science because it does not employ an experimental design. As we will see later in this handbook this is not strictly the case.

Natural resource managers are required to undertake monitoring to maintain their decision support system. At the same time, these agencies have great difficulty in sustaining long-term monitoring programs as a result of the continuous re-allocation of



resources driven by the electoral and budgetary cycles. The general response in environmental reporting (eg. State of the Environment SoE reporting), is to invent low cost substitutes for environmental condition based on some existing, albeit remote, source of information. The substitute measures employed in the absence of effective bio physical monitoring usually provides little information on incipient change (ie. that would be useful for providing early warning). They record the changes that have happened and not the ones that might or about to happen. Natural resource managers would appear to have much to gain from an effective engagement with citizen science,

although this has yet to happen in Western Australia.

In practice, most citizen science monitoring programs will operate as partnerships between interested community participants, with varying levels of technical competence, and fully trained 'professionals' making their contribution as citizens, rather than as employees of agencies, research or educational institutions or businesses. Retired, semi-retired and under employed professionals and research students may have a particularly important part to play in guiding citizen science programs.



Why 'Citizen' Science?

We have been conditioned in our market-based society to a role as consumers, defined by what we use and at what price. Many in our society would much rather define our place in terms of what we contribute, by what we do and who we are. The use of the word 'citizen' with respect to the concept of community based science has at least two distinct connotations. One is simply that such science is not necessarily 'amateur' in the sense that it is inexpert or lacks rigor. The second is that citizen science, as an activity,

is motivated by the need to gather information that is independent of that generated by commercial objectives or the environmental regulatory process and addresses otherwise unresolved community priorities for knowledge. In short, in a society where decision-making is heavily influenced by information (and who owns it), citizen science is about greater community empowerment.

Monitoring broadscale issues such as the ecological impacts of climate change or the effectiveness of natural resource management strategies are the responsibility of state governments, however, such programs are often not effectively resourced. The few government monitoring programs that do exist are limited to assessing the resource condition for profit making sectors of the economy, for example, the six most valuable WA fisheries, mining operations, and forest products, and rarely extend to monitoring the condition of the ecosystem from which the resources are extracted.

The proponent pays system which underpins the Australian environmental impact assessment (EIA), ensures that the characterisation, assessment and monitoring of ecological values in the context of development projects is

largely controlled by the environmental consultancy industry. Due to the direct financial relationship the consultancy industry has with their clients it is perhaps not surprising that there is a high level of community scepticism about the information supplied to the public in the Commonwealth and State's environmental assessment processes.

It should be understood that under the proponent pays system public assessment documents will not be designed to neutrally inform but to 'sell' a particular project to the stakeholders and lessen potential opposition from respondents. They are, at least in part, public relations products which should never be accepted on face value. In some Western Australian cases citizen science has already had an important role in debunking the information provided by proponents, or their agents, and in contesting the scientific 'spin' that characterises much of the EIA documentation and the reporting of monitoring results. Given that the proponent controlled EIA process is unlikely to be replaced with a more independent system (due to the potential cost to government), increasing the citizen science capacity in this area might be of considerable value to future respondents.

EXISTING BROADSCALE CITIZEN SCIENCE MONITORING PROJECTS

Project	Organisation	Monitoring activity
Alcoa Frogwatch	WA Museum - Alcoa	Program is mainly focussed on frog education and conservation. Frogs are potentially sensitive indicators of climate change and the presence of contaminants in the environment. Frog records are managed by the WA Museum.
Bird Atlas / Birds in Backyards / Surburban Birds	Birds Australia & Birds Australia WA	Several 'atlas' style projects are operating nationally in WA where participants report lists of birds encountered at registered localities. Methods vary slightly depending on the project. The Bird Atlas projects have been instrumental in documenting trends in the distribution and abundance of Australian birds.
ClimateWatch	EarthWatch Australia	This is a national coordinated monitoring project using public records of phenology (the timing of biological events) to climate change impacts. Observations are being collected on a wide range of common, indigenous and introduced, plants and animals.
Reef Check	Reef Check Australia	A national extension of an international program engaging divers and snorkelers in monitoring the condition of coral reefs using a standardised protocol. A temperate waters program has now also been developed.
Ecocean Whale Shark Monitoring	ECOCEAN	The ECOCEAN Whale-shark monitoring program uses divers to photograph a standardised area above the pectoral fins. The spot pattern in this area can be used to identify and track individuals. The program manages an international photo-library for Whale-shark identification and a database of Whale-shark sightings. The project is focussed on international Whale-shark conservation.
WaterWatch WA	Ribbons of Blue	Participants take physical and chemical water quality measurements and sample macro-invertebrates from streams and wetlands.

ECOLOGICAL MONITORING

Monitoring is commonly understood as an activity designed to detect change in something we value in order to provide for timely intervention. However it has to be said the results of many monitoring programs are not well designed, produce ambiguous results and, as a consequence, are of marginal value in informing decisions. Existing monitoring guides and handbooks tend to provide a number of techniques but neglect to place the activity within any strategic or experimental design. Whilst a variety of ecological monitoring techniques will be presented as examples or case studies in this handbook the emphasis will be on establishing the fundamental elements of a project and program design.

Survey, Surveillance & Monitoring

Goldsmith (1991) provided a number of definitions for activities associated with collecting environmental information, these being survey, surveillance and monitoring.

SURVEY

An exercise in which a set of qualitative or quantitative observations are made, usually by means of a standardized procedure and within a restricted period of time, but without any preconception of what the finding ought to be.

In the context of ecological survey the activities would be directed at determining what plant and animal populations and habitats are present at a particular location at a particular time. More sophisticated surveys may also document some of the ecological relationships that currently exist between key biological components across the habitats.

SURVEILLANCE

An extended program of surveys, undertaken in order to provide a time-series, to ascertain the variability and/or range of states or values which might be encountered over time (but again without any preconceptions of what these might be).

Surveillance activities dominate in most areas of natural resource management particularly where there are unknown, unspecified or multiple potential pressures or threats. Surveillance may well detect change but will provide little direct information on causality and is therefore limited in its capacity to inform management interventions. Time-series data, sufficient to determine the extent of natural or background

variability, are an important precursor to designing effective monitoring programs.

MONITORING

Intermittent (regular or irregular) surveillance carried out in order to ascertain the extent of compliance with a pre-determined standard or the degree of deviation from an expected norm.

The construction of an ecological monitoring program therefore requires a clearly articulated environmental objective, the identification of the relevant environmental stressors and the selection of appropriate bioindicators based on a prediction on how these organisms might respond when exposed to the stress. The key difference between surveillance and monitoring programs is the development of an experimental design to isolate the incidence and/or impact of a specific environmental stress (eg. a pollutant emission, local overfishing, changed fire-frequency, a weed or feral animal population or biological responses to change in rainfall patterns or sea temperatures).

Survey, surveillance and monitoring can be seen as a progression.

Ecological monitoring programs could hardly be designed for areas where there is insufficient basic information on biodiversity and the potential bioindicators. Predictive models for bioindicators require reasonable information on the extent of background variation (ie. change that naturally occurs in the absence of the local human impacts) and this information has to be obtained through the construction of time series through surveillance, either in the proposed monitoring area or a comparable environment elsewhere. Generally basic biological survey information

is assembled during environmental assessment processes but extended periods of observation are usually lacking at the time projects or programs are implemented. Methods of dealing with this problem are considered later in this handbook (see BACI design).

Monitoring Applications

Monitoring has three general purposes (Goldsmith 1991). These are

1. Assessing the effectiveness of policy or legislation;
2. Regulatory (performance or audit functions); and
3. Detecting incipient change ('early warning').

The one most relevant to ecological monitoring is the detection of incipient change that may be the precursor to a decline in resource condition or biodiversity values. However, in effect, the various purposes ascribed to monitoring overlap considerably. For example the detection of an incipient ecological change caused by changes in fire frequency might have immediate implications with regard to prescribed burning policies or biodiversity conservation legislation.

Western Australian environmental regulators (eg. the Environmental Protection Authority) have rarely set approval conditions or pollution limits based on bio-indicators, probably because these are too difficult to devise with the information available and expensive for government to verify. Wherever possible automation, in the form of physical or chemical sampling equipment and remote sensing technologies are used in preference to people (or staff time) to minimise the cost of collecting monitoring data. However community groups can readily utilise bioindicators to detect pollutants

and other impacts beyond the limits of project boundaries. Although such data could rarely be applied to existing regulatory standards, or project or pollution licence conditions, it could be used to accumulate evidence of unauthorized impacts or environmental harm.

Baselines, Benchmarks & Reference (Control) Sites

Standards, or measures of the 'background' or undisturbed condition, are essential for defining management objectives. Monitoring programs need to be designed to detect trends in these measures and provide early warning of an impending deviation from the objectives. Objectives set for ecological condition will generally be based on data from the surveillance of sites that are undisturbed by the environmental stressor(s) that are being managed. Objectives set for biodiversity conservation might be derived from measures of species richness or diversity in representative habitats or the distribution, population size or demography of specific plant or animal populations in a management area.

The term **baseline** is frequently used in the context of monitoring programs and generally refers to the state or condition of the indicators prior to a project or activity commencing. The so-called baseline is normally derived from short-term survey data collected in a pre-development or impact period.

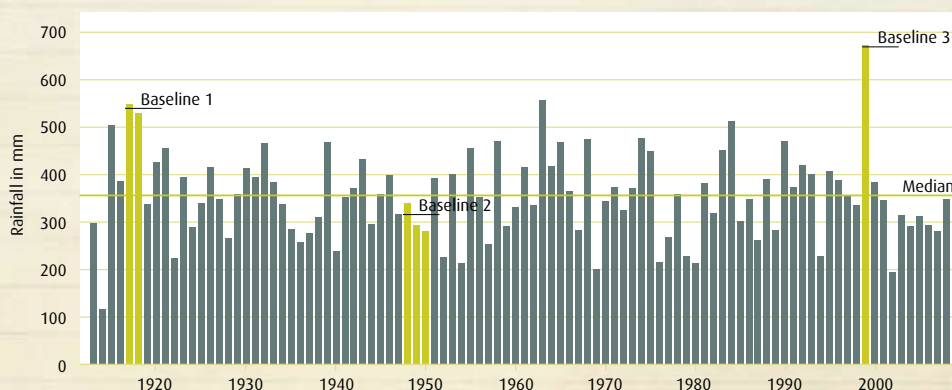
However ecosystems are constantly changing in response to chance (stochastic), successional and cyclical events regardless of human impacts. The short periods associated with survey activities are most unlikely to be representative of the long-term average condition and provide no information on the amount of background variation to expect. Extended periods of surveillance monitoring are needed to arrive at baseline measures with the degree of precision being dependent on the length of the time series. Unfortunately with respect to indicators of ecosystem condition or biodiversity such historical time series are extremely uncommon in Western Australia.

All Western Australian marine and terrestrial ecosystems, even in remote areas, have been subject directly or indirectly to the novel stresses caused by European colonisation. All environments have seen some degree of ecological change (eg. mammal extinctions, introduced animals, weeds, decline of fish stocks). There are no unaltered baseline ecosystems or habitats available for reference. The initial surveys of project or management areas are called **benchmarks**, a snapshot of the situation at a particular time. Benchmarks, as is the case with baselines, will not be representative of the long-term 'normal' condition unless they are derived from a significant period of surveillance and encompassing the likely extent of background variability (*see figure below*).

The problem with obtaining defensible baselines or benchmarks underpins the utilization of reference sites to monitor ecological impacts. **Reference sites** are representative areas of habitat outside the predicted impact area for a particular stressor. They are analogous to 'controls' in an experimental design but of course many variables operate in natural environments which we cannot exclude. This problem can at least be partially overcome by ensuring there is sufficient replication of reference sites to filter out any localised variations and detect the broad-scale 'background' changes occurring in the ecosystem at the time.

Management objectives can be constructed from measures of the deviation of 'impact' sites from the background variation observed in the reference sites. Ideally, habitat matched reference and impact sites should be established and observed before a proposed project or management action is implemented and then monitored periodically thereafter. This approach is referred to as a **Before – After – Control – Impact (BACI)** design. BACI approaches have a range of applications from the monitoring of localised project impacts, such as a mine, a marine aquaculture development or the introduction of a genetically modified crop. Similar approaches could also be applied to the broader adaptive management programs such as multiple-use marine reserves or rangeland grazing strategies.

**LONG TERM ANNUAL RAINFALL PATTERN AT DALWALLINU
SHOWING ALTERNATIVE AND SHIFTING BASELINES.**



Data from Climate Data Online, Bureau of Meteorology 2009

Extended periods of surveillance monitoring are needed to arrive at baseline measures with the degree of precision being dependent on the length of the time series.

Bioindicators

A **bioindicator** is an attribute at any level of biological organisation that by its presence, absence, quantum, condition or behaviour indicates something about the state of the environment (adapted from Spellerberg 2005).

Bioindicators have a number of advantages over the measurement of physical or chemical parameters in monitoring environmental change. These advantages include;

- the ability to integrate changes to ecological processes at different levels or over a range of spatial scales;
- the ability to capture and retain information on the incidence of past events (eg. a short-term spike in a pollutant) or accumulating impacts (eg. marine eutrophication, climate change);
- the ability to provide information on the ecological consequence as well as the incidence of a stress factor (eg. heavy metals or pesticides in the environment);
- the utilization of observations that are generally less reliant on specialized, automated technology;
- the utilization of subjects that are more engaging (to the general public) and of greater social significance (eg. wildlife).

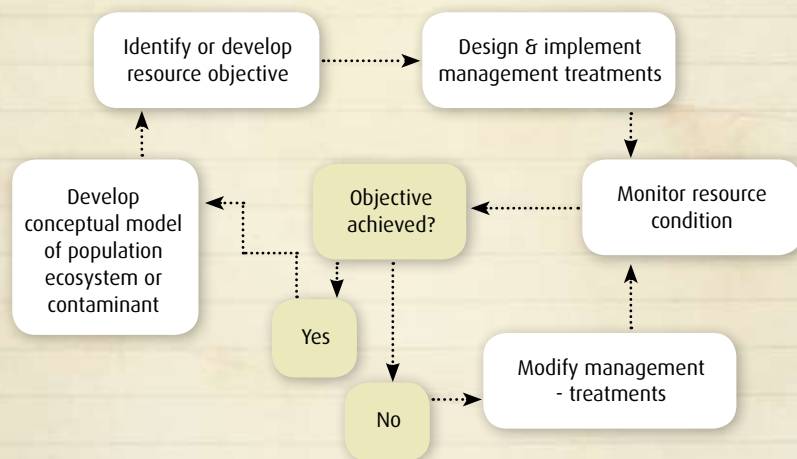
The disadvantages of bioindicators are that they are usually more labour intensive (and therefore more costly to monitor), more logically complex to construct and interpret and difficult to standardise. As such they are less likely to be used in a regulatory context in setting unambiguous legal limits. In general the characteristics of bioindicators make them more suitable for community based monitoring or citizen science. This handbook therefore deals therefore primarily with the use of bioindicators.

Adaptive Management

Ecosystems are far too complex for us to understand the behaviour of each individual component. However, we can improve our ability to predict the impacts of human activities by practicing **adaptive management**, a process of learning by doing.

Within an Adaptive Management framework resource utilisation or management prescriptions/ treatments are carried out in the context of an experimental design. Typically, different treatments are applied to separate representative spatial areas or zones. Good designs will have representative 'reference' areas that are free from the human impact pressures that are being assessed.

Monitoring is the cornerstone of an adaptive management system. It provides the 'decision support system', the critical information on whether the resource condition objectives are being met by the management prescription. If they are not, the management strategy will require modification or replacement based on improved conceptual model of the system.



Australian bird & bat banding scheme

To monitor incipient changes in animal populations we might need to know about the life-histories of individuals. Since as humans we have great difficulty reliably identifying individuals in most species, we need to mark our subjects or year groups (cohorts) and track their progress. Most developed countries have centralised bird and bat banding (ringing) schemes coordinating the use of numbered or coloured bands in studies by both professional and amateur biologists. These schemes typically take responsibility for supplying bands and equipment and for the training and licensing of banders. The schemes also manage the core data collected on all marked individuals in a centralised data-base.

Bird-banding has a long history and has made a significant contribution to the sciences of ornithology, ethology (animal behaviour) and population biology. Historically much of it was done by amateur enthusiasts, although the practice is becoming increasingly restricted to people with some professional training. Animal marking can be used to monitor migration, dispersal, territory size, mate fidelity, site fidelity, social relationships, age of first breeding, reproductive performance, recruitment, longevity, age structure, and mortality rates. It can also be used to allow individuals to be re-sampled over time for body condition, contaminant burdens, growth rates, food intake, moult and so on.

The Australian Bird & Bat Banding Scheme (ABBBS) coordinates bird-banding nationally. Most licenses require an apprenticeship period supervised by an experienced bird or bat bander. The scheme also licences the use of otherwise prohibited traps such as mist-nets and cannon-nets which are frequently required for bird / bat banding operations. Western Australian Wildlife Conservation Act (1950) permits to 'Take & Mark' fauna are also required to authorise bird and banding projects. Information about banding methods, training, licensing and data access can be sourced from the ABBBS Website <http://www.environment.gov.au/biodiversity/science/abbbs/> or by contacting the office (02) 6274 2407.



Selecting Bioindicators

There are a variety of technical, logistic and social considerations in the selection of bioindicators. Technically it is essential that the indicator is underpinned by a conceptual ecological model (Elzinger et al. 2001), a prediction of how a particular population, biological community, morphological trait, physiological state, behaviour or contaminant burden might change in response to an existing or anticipated environmental stress.

Being able to do this implies that:

- The taxonomy of the subject species, guild (ecologically groups) or biotic community is well known at the required level of classification;
- The relevant aspects of the subject's biology or ecology are well understood; and

A consistent sampling methodology has been devised that can provide data in a form that services the indicator.

The logistical considerations include the availability of appropriately skilled and motivated citizen scientists,

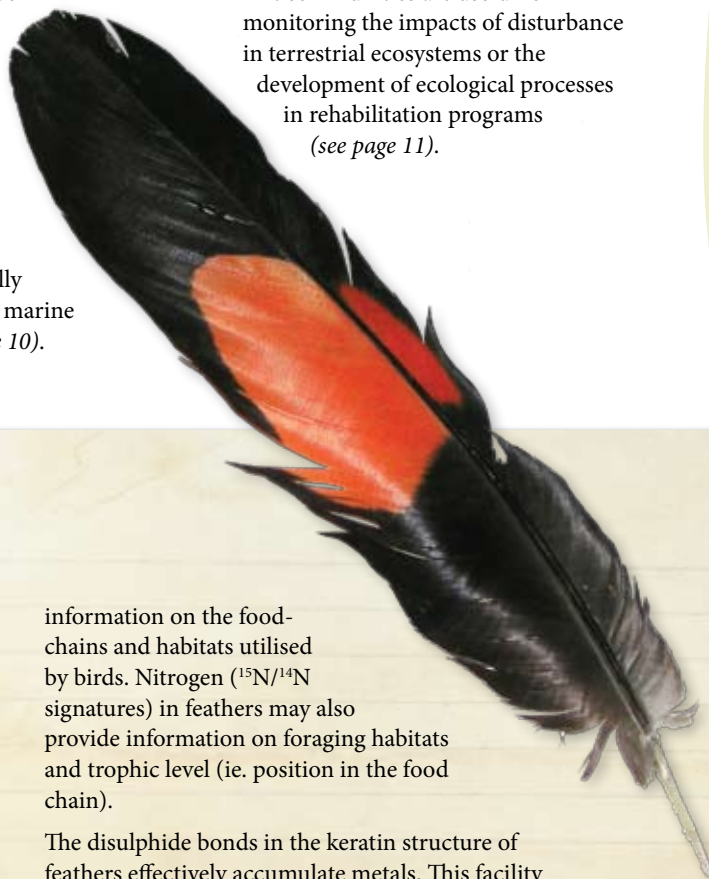
reliable access to monitoring sites, security of monitoring sites (ie. protected from public interference), the weather dependence of the sampling methodology, vehicles or vessels required, distances travelled, accommodation, equipment cost and availability and the safety of participants. The degree to which a proposed program will require establishment and/or recurrent funding is obviously an important issue, as is the identification of potential sources of the financial or in-kind support required.

Social considerations include the relevance of the program to the community, the value placed on the monitored environment, the popularity of the indicator subject(s) and whether the results (changes to the indicator) will be comprehensible and easy to communicate to the community in general and to decision-makers. The reporting format and frequency may have an important bearing on whether the results are picked up and

utilised in an adaptive management framework.

Seabird species or guilds are an example of subjects that have technical, logistic and social characteristics that make them potentially useful indicators for marine ecosystems (*see page 10*).

Ant communities are useful for monitoring the impacts of disturbance in terrestrial ecosystems or the development of ecological processes in rehabilitation programs (*see page 11*).



What's in a feather

Feathers wear and are shed and then replaced periodically in the moult. Once fully grown a feather is isolated from the bird's circulatory and nervous system and is held in place in its follicle by non-living connective tissue. Lost or extracted feathers are generally replaced within a few weeks, even outside the normal moulting period. Feathers, like mammal hair, are derived from skin tissue and constructed of the protein keratin. However, unlike hair, the potential ecological information incorporated in a feather's structure can be readily related to a discrete time window, to the period over which it was growing.

The sampling of moulted or moulting feathers is a relatively unobtrusive method of obtaining monitoring data from birds. The extraction of un-moulted feathers is also benign as long as it operates within the limits of feather loss occurring during the natural moult.

The rate of feather growth is influenced by the bird's nutritional condition which, in turn, will be determined by the individual's access to food resources. This access to food will, in turn, depend on the individual's quality or 'fitness', on the pressures of density-dependent competition and on variations in food production. Environmental contaminants may also impact on bird health thus influencing feather growth.

The feathers of many species have discernable light and dark growth bars which reflect daily growth increments. These growth bars (analogous on a short time scale to tree-rings) along with other measures of relative feather growth rates can be used to monitor changes in nutritional condition. The term *ptilochronology* (meaning feather-time) has been coined for this method (Grubb 2006).

Other approaches utilising feathers in ecological investigations could be termed *ptiloassay* (feather composition analysis).

The protein keratin is ideal for cost-efficient stable isotope analysis (as it does not require lipid or calcium extraction processes). The analysis of the carbon ($^{13}\text{C}/^{12}\text{C}$) stable isotope ratios in feathers can provide

information on the food-chains and habitats utilised by birds. Nitrogen ($^{15}\text{N}/^{14}\text{N}$ signatures) in feathers may also provide information on foraging habitats and trophic level (ie. position in the food chain).

The disulphide bonds in the keratin structure of feathers effectively accumulate metals. This facility has led to bird feathers being used quite extensively to detect metal contamination in both marine and terrestrial ecosystems. Birds preferentially sequester some toxic heavy metals (eg. mercury) in their feathers to reduce the internal burden accumulated by their ingestion of food, water and other materials. Feathers also efficiently capture and bind metals from external surfaces such as dust on vegetation. Metal monitoring programs need to be designed with some understanding of the various potential contamination pathways.



Seabirds as ecological indicators

Seabirds by definition are marine animals. They are particularly useful as bioindicators of trophic (food and productivity) conditions within marine ecosystems because:

- Most are **higher order predators** near the apex of marine food-chains and therefore integrate the bio-physical processes operating in those ecosystems.
- They are **colonial nesters** (mostly on islands), predictable in location and time facilitating the repeated sampling necessary for monitoring programs.
- They are **central-place foragers**, when breeding, with different species having specific foraging ranges. This provides opportunities to monitor changes on a range of spatial scales from 101 to 104 km².
- Different species **occupy a range of marine ecosystems** from estuarine to coastal, continental shelf to oceanic. Information of changes in different marine ecosystems can therefore be monitored from one focal location.
- The high energy demands associated with rearing young lead to marked variations in reproductive output. **Breeding performance is a robust indicator of prevailing, within-season, oceanographic and trophic conditions.**
- **Pelagic seabirds have conservative life histories**, eg. strongly philopatric, long-lived delayed maturity, low capacity for increase and rest years. Changes in population size and/or distribution reflect trends in marine ecosystems and not short-term spikes.
- **A curious mixture of tropical and temperate cool-water species** share breeding islands off central and south-west WA due to the presence of the Leeuwin Current. Changes in seabird community composition and structure are potential indicators of shifts in ocean climate.
- They are **visible and 'popular' subjects for observation** increasing the potential for participation in monitoring programs.
- There is, for central west and south-west WA, **a useful historical record** of breeding distribution dating back to the colonial period.



Sampling Design

Biological populations and ecosystems cannot be observed in their entirety so we rely on information from a representative subset of units, **a sample population**. The characteristics of a sample population determine its statistical power, ie. the capability to discriminate trends against the probability that the results could be the outcome of chance events. An effective sampling design has a number of basic technical attributes such as the independence of sampling units, a relevant spatial distribution, frequency and intensity, an appropriate unit size, and a sufficiently large sample size (ie. the number of samples) to

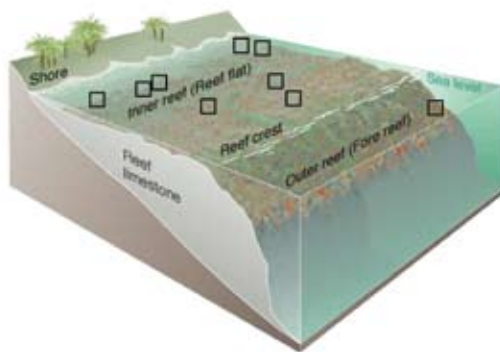
encompass the range of natural variation and replication to reduce the affects of error and uncertainty (Goldsmith 1991, Elzinga *et al.* 2001) in the results. The technical requirements need to be optimised with the logistical and cost implications to arrive at a program that is both defensible and practicable.

INDEPENDENT SAMPLING

Sampling must be done in a way that does not predetermine the results and sample-units must be independent of each other in both space and time. Pure random sampling will satisfy these requirements but may be inefficient, requiring an excessive number of

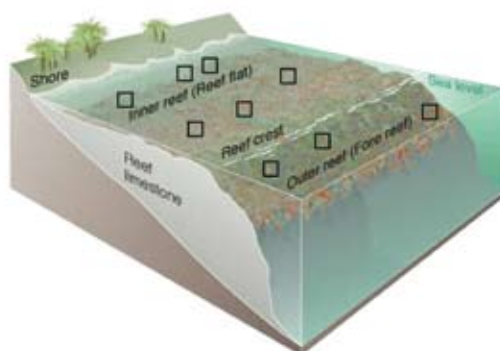
samples to get the required spatial or temporal coverage. The technique most often employed is '**stratified random sampling**'. In stratified random sampling the samples are allocated proportionately between different predetermined zones (eg. habitats or management treatments) or time windows (eg. months or tide cycles) that are representative components of the system being monitored. Within each spatial zone or time window the sample units are randomly distributed (ie. without reference to what is present in the sample site or what is happening).

Diagram showing random and stratified random sampling



Random Sampling

In random sampling, all samples have an equal chance of being selected from the population. In this example, nine quadrats have been randomly chosen on a reef to measure hard coral cover. Due to the random selection of quadrats, the outer reef habitat has not been equally represented in the data collection.



Stratified Random Sampling

In stratified random sampling, the reef is now divided into three strata (inner reef, reef crest and outer reef) and the quadrants are randomly selected from the strata. The chosen samples are now more representative of all the possible samples.

Coral reef diagram courtesy of the US Geological Survey

The focus of many ecological monitoring projects is however going to be on the changes occurring at a particular sampling site (monitoring plot) that is revisited periodically or in a particular marked population. The samples in these time series are not independent as what has occurred in the past will influence what occurs in the future. For example many of the perennial plants recorded in a vegetation monitoring plot at time (t) will have survived to be observed again at time (t+1). The age structure at a seabird colony (t) will still be contributing to the demography of that colony at (t+5) along with changing environmental factors. This problem known as auto-correlation

Ants & ant communities as ecological indicators

Ant community structure has been used as an ecological indicator in Australia since the 1980s (Andersen 1990, Majer & Nicholls 1998, Spellerberg 2005).

- Ants are the dominant epigeic (soil-surface) invertebrates in Australian terrestrial ecosystems.
- There is significant but not overpowering ant biodiversity.
- Ant communities function on relatively localised 'within vegetation type' or 'habitat patch' spatial scales compared with potential vertebrate bio-indicators.
- Ants are either generalist omnivores or predators and as higher-order consumers have the capacity to integrate a wide range of ecological processes.
- Ants establish long-term nests but also have very efficient dispersal mechanisms. As such, a great variety of ant species are available to colonise most habitats.
- The number of ant species in a habitat is generally a good predictor of other invertebrate and vertebrate biodiversity.
- Ants are an ecologically important functional group in their own right, being involved in processes such as bioturbation (soil turnover), nutrient cycling, pollination,

seed dispersal and removal, plant and invertebrate symbioses and predation (Keller & Gordon 2009).

- The relative abundances of the species with a community are sensitive to relative low levels of disturbance and are therefore effective for detecting incipient change.
- The taxonomy of Australian ants is relatively well known at the generic level and suitable guides are available (eg. Shattock 1999). It is not necessary for most applications to identify specimens at the species level (generic morphological types or functional groups are sufficient for most monitoring programs).
- Ants are easy to sample and preserve.

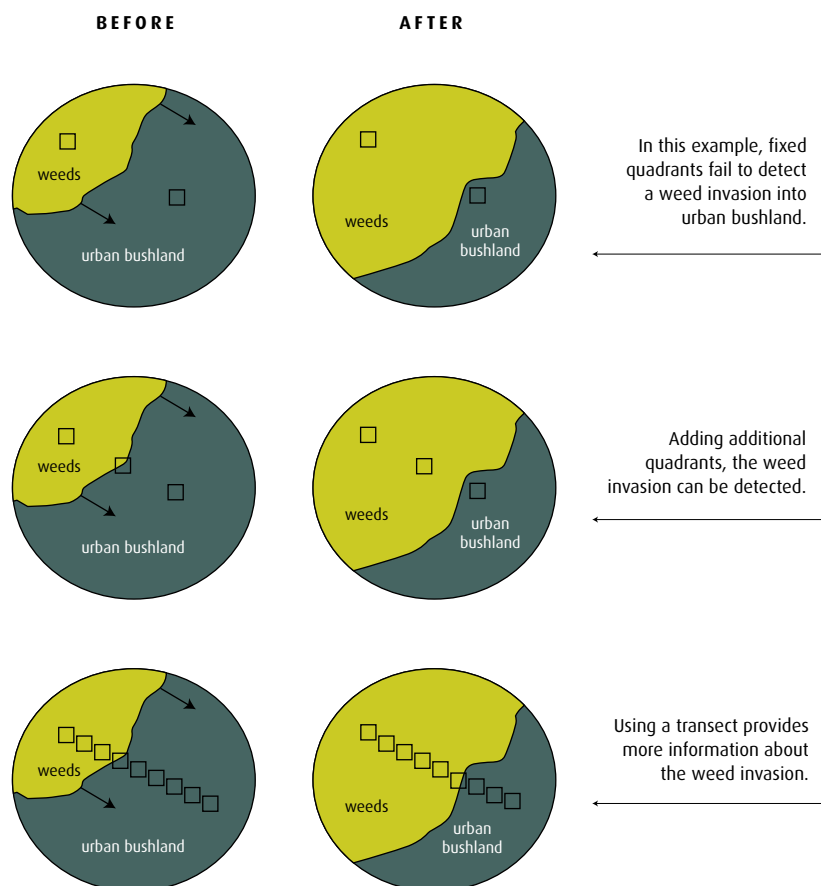


limits the statistical analyses that can be applied to fixed plot or population time-series data. One way of dealing with this problem is not to avoid **auto-correlation** but to analyse the pattern of peaks and troughs in the time series in relation to the cycles in environmental variables.

SPATIAL DISTRIBUTION, FREQUENCY AND INTENSITY OF SAMPLING

The **spatial distribution** of sampling will be determined in part by the stratified random framework. However there may be other important considerations particularly where the

stress factor being monitored may occur at the edges of the system (eg. a weed invasion into urban bushland) or operate along an environmental gradient (eg. *Phytophthora* dieback on a hill slope). Here sample sites will need not only to be stratified by habitat type but arranged such that they straddle (and therefore detect) the boundaries between affected and unaffected areas. The edges or boundaries of systems are the most dynamic and it is important that the layout of sampling plots of transects picks them up. If all the sampling sites are in core unaffected areas or totally impacted areas they may be unable to provide warning of an approaching front, of incipient change.



The **frequency** of sampling will depend on your bioindicator and the likely response interval it has to the stressor being monitored. There are usually also seasonal constraints on when the relevant observations can be taken (eg. end of growing season, flowering period, activity windows in fauna, breeding seasons and so on). It is generally good practice to standardise monitoring observations between particular dates to reduce

the variability from seasonal factors. The early 'surveillance' phase in a monitoring program is important to establish the range of inter-annual background variability and during this phase observations will probably be required on at least an annual base. Once a substantive time series has been established and the factors influencing background variability are understood it may be possible to reduce the sampling frequency for the longer term.

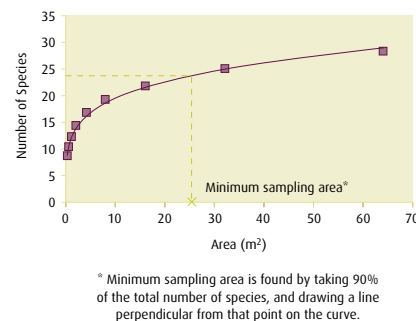
Sampling intensity is largely a function of bioindicator abundance. Common and predictable faunal indicators require less effort than uncommon ones. For most vegetation monitoring the intensity of sampling will remain constant once the appropriate sampling unit has been determined (see right). However, the ability to detect, observe or capture mobile bioindicators (ie. animals) may vary significantly between years. Servicing faunal indicators may require variations in sampling intensity (eg. trapping effort, census area) to ensure that minimum sample sizes are maintained. Measures of abundance can of course be standardized for observer effort.



THE SAMPLING UNIT

Sampling units should be determined from survey or surveillance data or extrapolated from experience elsewhere in similar ecosystems. For plants, vegetation or sessile animal (eg. corals) parameters, the appropriate size for a sampling unit (eg. sample plot, quadrat, or belt transect) can be determined using species-area curves. Starting at the origin the sample area is increased (eg. 1m², 2m², 4m², 16m²...) and the additional species encompassed are recorded each time. Common species accumulate first whilst relatively rare species may only be encountered in the larger sample areas. Typically for sampling within a habitat an initially steep curve flattens to an asymptote which represents the area necessary for the expression of a plant community (see figure below). Similar curves can also be used to predict the expression of a particular plant species which may be more relevant if a species level ecological indicator has been selected. Crossing habitat boundaries will produce new steps in the species accumulation curve indicating that you are sampling on a habitat boundary.

Hypothetical species-area curve.

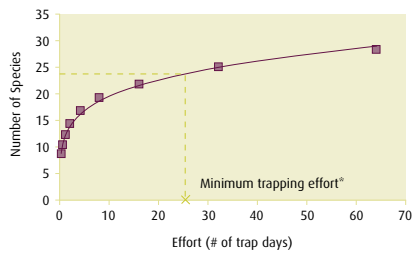


For mobile animals it is our ability to capture or otherwise detect species that determines the necessary sampling units. In this case sampling area is replaced with measures of sampling effort (the product of the number of traps or observers and time). Units might be standardised for example, as the number of trap-days or observed area per hour. Species-effort curves can be generated in much the same way as for species-area but in this case additional species are accumulated against increasing effort units for sampling within a habitat. Species-effort curves derived from survey or surveillance data or from experience in similar ecosystems can be used to define units that encompass the minimum effort required to sample the selected indicator (eg. 100 spring or summer

pit-trap days per sample site).

Animal activity and therefore capture or detection probability varies considerably between seasons. Steps in the species accumulation curve (for sampling extended over a significant period) reflect these changes in activity. With faunal indicators it may be necessary to standardise sampling to a particular seasonal window where there is sufficient activity to sample efficiently.

Hypothetical species-effort curve.



* Minimum trapping effort is found by taking 90% of the total number of species, and drawing a line perpendicular from that point on the curve.

SAMPLE SIZES

Our ability to discover trends in monitoring data will be strongly influenced by the number of samples (ie. the number of times the sampling unit has been replicated) and the amount of variation around the mean value (eg. the standard deviation). This ability is referred to as statistical power. The more samples (or replicates) are producing similar values the less probable it is that the observed trends will be the result of chance. Conversely the more variation there is, and resulting overlap between sample populations, the more likely it is that the differences observed between means or medians are not real, or 'statistically significant'.

Generally the greater the variation in the samples the larger the number required to provide sufficient statistical power. An estimate of the standard deviation for a particular metric (measurement) might be obtained during the survey or surveillance phases of developing a monitoring program. However it is generally advisable to pilot a proposed monitoring program to determine the level of variability in the indicator metrics before settling on a long-term sample-size. Regardless of the statistical considerations it is also important in ecological monitoring that the sampling is sufficient encompass the range of natural variation present.



Planning a Monitoring Program

The key elements of a monitoring plan include:

1. **Background** – an explanation of the environmental reasons for the monitoring program and the socio-political factors that necessitate the engagement of citizen scientists in its implementation.
2. **Management objectives** – an explanation of the management objects that the monitoring program is designed to support.
3. **Description of the ecological model** – an explanation of the expected interactions between the selected ecological indicator (s) and the stressors of management concern.
4. **Indicator construction** – an explanation of how the monitored subject and its attributes were developed from the ecological model.
5. **Sampling design and metrics** – an explanation of how the attributes will be sampled and measured to service the indicator (s).
6. **Resources and partnerships** – Identification of critical resources and important partnerships that will be necessary to successfully implement to monitoring program.
7. **Reporting** – Description of reporting method, format and frequency.
8. **Communications** - Identification of the target audience (s) and media for the reporting. A strategy to engage the community and decision-makers with the results.
9. **Pilot Projects** – A description of any preliminary research, survey or surveillance results, test-sampling or statistical evaluation that was conducted to prepare the indicator for long-term monitoring. May be an Appendix to the plan.

Getting permission

Many ecological monitoring programs will involve the collection of protected flora specimens for identification and/or the capture, marking or 'taking' of protected fauna. The monitoring activities will also need to occur with the authority of the private land owner or the public land/marine managers. Permission or exemption may also be required to possess and use a restricted trap of sampling device, such as a mist-net for birds and bats or a research (small mesh) purse-seine net for fish.

In Western Australia all indigenous higher plants (angiosperms), mosses & lichens (bryophytes) and seaweeds (macro-algae) are protected under the Wildlife Conservation Act 1950 as are all terrestrial vertebrate animals (frogs, reptiles, birds & mammals) and some selected invertebrate groups (eg. jewel beetles and butterflies). Other biota may be declared protected over time using the Regulations. Many terrestrial invertebrates (eg. ants & termites) used in monitoring are not currently protected other than in conservation reserves. The sampling of fish (all aquatic organisms other than frogs, reptiles, birds and mammals) may be subject to the Regulations of the Fish Resources Management Act (1994).

Threatened or specially protected species require specific State dispensations and if listed under the Environmental Protection & Biodiversity Conservation Act (1999) may require approval from the Commonwealth Department of Environment, Heritage & Water. However, threatened species are unlikely to be appropriate subjects for citizen-science based ecological monitoring programs.

An important element of preparing a monitoring program is to ensure that all the planned sampling activities will be lawful.

A minimum requirement for most programs will be two licenses or permits, a license to collect or capture (from the Department of Environment & Conservation - DEC) and an access permit (with the origin depending on the land tenure).

Activities involving the capture, handling, tagging or blood/tissue sampling of vertebrate animals may also trigger the requirement for Animal Ethics approval. If the sampling activity involves partnerships with institutions, such as the Universities, ethics approvals can be obtained from their in-house committees. The Animal Ethics considerations for independent projects that do not involve institutions or agencies are reviewed by DEC as part of the process of issuing permits to take or mark fauna. Licensed bird & bat banders are covered by the Animal Ethics accreditation pertaining to the animal welfare procedures of the Australian Bird & Bat Banding Scheme.

In issuing fauna permits the DEC will need to be satisfied that the principal license holder has sufficient training and experience to manage the sampling effectively and responsibly. The development of a monitoring project may therefore depend on group membership or project partnerships that engage a person or group with the appropriate qualifications.

Discovering or Framing Management Objectives

Scientific research is what we do when we don't know the answer. Ecological monitoring is also a scientific activity but it is designed to utilize what we do know about biological systems to detect changes that may compromise (incipient changes) or have already impacted (state changes) management objectives. Clear articulation of management objectives is therefore fundamental to the development of a monitoring program.

Commonwealth, State and Local government agencies with responsibilities for natural resource management may have general ecological objectives articulated in statements of policy, guidelines or

management plans. Unfortunately these are often 'high level' without the six key components needed to underpin effective monitoring and auditing of management outcomes. The six components (adapted from Elzinga *et al.* 2001) are:

1. An identified indicator (the observed or measured subject eg. a species or biotic community);
2. The location (geographic area);
3. An attribute (the aspect or characteristic of the indicator being observed or measured);
4. The desired trend (decreasing, stable, increasing);
5. The quantity or status (the degree of change in the attribute to be detected); and
6. The time frame (the period over which the monitoring is required).

Government management objectives may also be reflected indirectly through Ministerial conditions on development proposals under Part IV of the Environmental Protection Act 1986, in planning approvals by the State Planning Commission, ministerial conditions on mining tenements under the Mining Act 1978 and through regulatory standards (ie. for emissions under Part V of the EP Act 1986). Unfortunately, as is the case with objectives set for the activities of agencies, those set for development projects, through approval conditions, have rarely been linked to ecological monitoring requirements and have as consequence been difficult to audit and enforce.

SOURCES OF OFFICIAL ECOLOGICAL OR BIODIVERSITY CONSERVATION OBJECTIVES

Subject	Authority	Source Documents
State biodiversity, fisheries, pastoralism and conservation.	Environmental Protection Authority	State of the Environment Reports.
National Parks & Nature Reserves.	Conservation Commission	Management Plans prepared by the Department of Environment & Conservation
Marine Reserves.	Marine Park's & Reserves Authority	Management Plans prepared by the Department of Environment & Conservation
Biodiversity conservation in WA.	Minister for the Environment Department of Environment & Conservation	DRAFT State Biodiversity Conservation Strategy
Local Government Reserve Management Plans.	Local Authorities	Local Authority Management Plans.
Western Australian & Commonwealth managed fisheries.	Commonwealth Department of Environment, Water, Heritage & Arts. WA Department of Fisheries	EPBC Act Fisheries Environmental Assessments
Fish Habitat Protection Areas.	Department of Fisheries	Fish Habitat Protection Area Management Plans
Perth coastal waters.	EPA – Western Australia	Perth Coastal Waters Environmental Values & Objectives.
Pilbara coastal waters.	EPA – Western Australia	Pilbara Coastal Waters Environmental Values & Objectives.
Ecological/biodiversity objectives associated with the approval of projects.	Minister for the Environment	Ministerial conditions on statements that a project may be implemented. Draft conditions in EPA reports to the Minister
Ecological/biodiversity objectives in regional Natural Resource Management (NRM) Plans.	Western Australia's six regional NRM Councils.	Resource Condition Targets (RCTs) in NRM Plans

Another problem is that natural resource management agencies tend to operate within narrow jurisdictional boundaries with poor integration of programs across landscapes and ecosystems, marine or terrestrial. The absence of 'whole of government approaches' to planning at bio-regional levels frequently leads to a mismatch of spatial scales and a plethora of poorly integrated, if not contradictory, management objectives. So where does that leave the citizen scientist?

Firstly, the community should avoid perpetuating the integration problems that beset government. If there are adopted management objectives related to the ecosystems of interest then they need to be 'discovered' and reflected in indicator construction and the monitoring plan. In most cases such objectives will be high level (eg. threatened species should not be protected from further decline) leaving most of the formulation work still to be done. Where there are protected area management plans or development projects there should be objectives with more local and immediate application (eg. a 20% decrease in the mean epiphytic green algae cover on perennial seagrass within the monitoring plots in



the Warnbro Sound by 2015) although unfortunately this is sometimes still not the case.

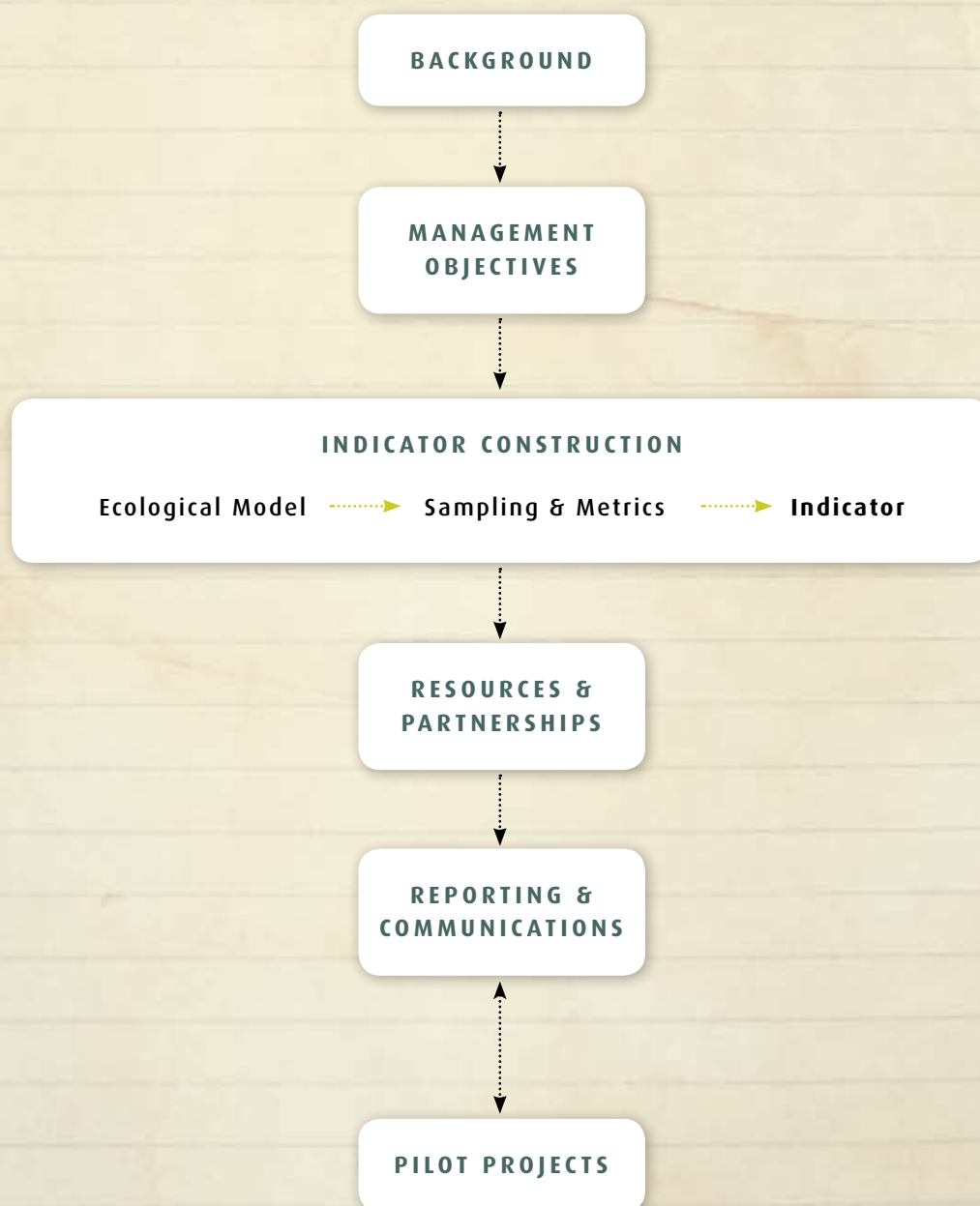
In the absence of existing management objectives operating at the appropriate scale, relevant ones will need to be framed. This may take place in the context of interest group engagement with official management planning processes or in the process of public consultation in project development or environmental assessment processes.

However ecological issues may also arise at the community level in the vacuum of inactivity by management agencies. In this context the framing of management objectives may result from a dialogue conducted between the interest group and its community. Such objectives may not initially have any administrative or legal legitimacy but might be proposed for adoption by the 'authorities' at an appropriate time.



PART B - PREFACE

This section of the handbook applies the structure developed for monitoring plans in Part A to four demonstration projects. These projects piloted a range of methodologies as a preparatory step in developing long-term monitoring programs. The four monitoring plans have the following structure.



BUSH CANARIES MONITORING PLAN

BACKGROUND

Between December 2006 and March 2007, areas within the Esperance township were exposed to fugitive lead (Pb) carbonate emissions from ship-loading operations at Esperance Port. The problem was detected following the sudden death of an estimated 4000 nectar-feeding birds (honeyeaters and purple-crowned lorikeets) in parts of the town. Post-mortem examination of a sample of these birds concluded that they had died from acute lead poisoning (Education & Health Standing Committee 2007), probably from nectar contaminated with lead carbonate dust. Inhalation and absorption through the lungs was another possible pathway for Pb intoxication. It is also possible that honeyeaters are more susceptible to Pb poisoning than other birds. Feral pigeons from the port area were showing higher tissue Pb levels than the honeyeaters with no apparent ill effects.

The bulk handling and shipping of lead carbonate concentrate was suspended in March 2007. Recent decisions will now see this material exported as a bagged and containerised product through the Port of Fremantle.

The bird mortalities were recorded from areas that were downwind of the port during prevailing easterlies and south-easterlies and extended up to 3.5 km inland and were mapped by the Department of Environment & Conservation. Subsequent investigations found lead with the diagnostic stable isotope signature of the Magellan ore (from the Magellan Mine west of Wiluna) on a variety of surfaces within the township: in the soil, surface water, rainwater tanks, vegetation and in blood samples taken from the nearby human population (Education & Health Standing Committee 2007).

Nickel sulphide concentrates have been loaded into bulk carriers at the port for more than a decade and monitoring results since 1995 have consistently shown that fugitive dust was settling outside the port management boundaries. The health and ecological implications of this had not been considered a matter of concern until relatively recently (Education & Health Standing Committee 2007).

Management objectives

The handling of bulk mineral products by the Esperance Port is conducted subject to the conditions of a licence issued under Part V of the Environmental Protection Act 1986. The Education & Health Standing Committee 2007 found that

the events leading to the contamination of parts of Esperance with dangerous lead carbonate dust were the results of failings by the Esperance Port, the Magellan Mining Company and the structure and resourcing of the regulatory system.

It was clear from the mass mortality of birds that fugitive lead carbonate dust was capable of causing significant environmental harm. Local bush birds had served as powerful indicators of an undetected threat to local marine and terrestrial ecosystems and public health.

The Bush Canaries project was initiated by the Conservation Council of WA (CCWA) and the local environment group Esperance LEAF in 2007. It was designed to monitor the extent and persistence of Pb contamination in the Esperance environment using birds and their feathers. The focus was not on bird health but on using birds as indicators of broader environmental state or health. During the pilot phase it also became apparent that bird feathers were also accumulators of fugitive nickel-sulphide dust and could be used to monitor the contamination from the ongoing nickel (Ni) concentrate export operations at Port.

There are no applicable standards for Pb or Ni contamination in plants or animals. The community aspiration was to restrict heavy metal contamination to levels consistent with the background levels expected in a small, rural coastal town. The objective was therefore to ensure that the Pb and Ni levels at sites impacted by Esperance Port operations between December 2006 and March 2007 did not remain significantly higher than those measured in local reference areas.

INDICATOR CONSTRUCTION

Ecological Model	Taxa / Community/ Functional Group	Metrics	Indicator
Bird feathers are efficient accumulators of metal contaminants. These metals may be sequestered in the feathers and reflect the internal (eg. blood) contamination burden or bound ectopically reflecting metal levels in the external environment (eg. on soil or vegetation).	Sixth primary feather of most abundant passerine (bush) bird species in impact and reference areas.	Concentration of lead (Pb) and nickel (Ni) in whole feathers expressed as mg/kg dry weight.	Difference between mean Pb and Ni concentrations (mg/kg) at impact and reference sites.

Resources & partnerships

The Bush Canaries project requires someone with a mist-netting authority (licence to mark fauna under the Wildlife Conservation Act 1950 and A Class Bird Banding permit from the Australian Bird & Bat Banding Scheme). Dr J.N. Dunlop from CCWA had the required authorities and equipment. Mist-netting operations and other sampling activities during the pilot project were carried out with the assistance of members of the Esperance community and volunteers from CCWA. These arrangements are expected to continue for the duration of the project.

Esperance LEAF allocated the funding for the first years laboratory analysis at the WA Chemistry Centre. However, following reporting of the first sampling results, the State Government, through the Department of Environment and Conservation (DEC), offered to fund the chemical analysis for a three year period.

Access to impact areas was required from the Esperance Shire, Water Corporation and private land-owners. DEC granted permission to take feather samples from birds and to sample at the Woody Island Nature Reserve as a reference site.

Reporting & communications

Reports have been prepared for the two pilot years and provided to government and the Esperance environmental groups. The results of the first years sampling were presented at a Locals for Esperance Development (LED) public meeting in June 2008. Results of the second years sampling were provided for a DEC open day in Esperance. Media releases resulted in extensive media coverage, particularly at the release of the first Bush Canaries report.

Annual reporting will continue until Pb & Ni contamination levels in the impact areas reach background levels. DEC is advised of results as soon as they become available.

Pilot projects

The results from the 2007 and 2008 Bush Canaries feather sampling were combined in the 2008 report. Community members were also enlisted to record the presence / absence of New Holland Honeyeaters in their gardens and local parkland. Over 50 Esperance residents participated but the sample sizes were nevertheless insufficient to provide for statistical analysis.

Monitoring point-source lead & nickel contamination of a terrestrial environment using common bush birds – 2008 report

Bird feathers have been tested and used extensively around the world as a bio-monitor for heavy metal contamination in both terrestrial and marine environments (Burger 1993, Dauwe *et al.* 2002, Dong-Ha Nam *et al.* 2004, Scheifler *et al.* 2006, Hahn *et al.* 1993, Golden *et al.* 2003, Swaileh & Sansur 2006.), although the investigations are somewhat biased towards seabirds and shorebirds. This investigation uses the feathers of common bush birds occurring within the Esperance townsite to monitor the extent and persistence of lead and nickel contamination from fugitive dust emissions

associated with the handling of lead carbonate and nickel sulphide concentrates at the Port.

LEAD (Pb) IN BIRDS & FEATHERS

Pb may become incorporated in, or adsorbed (bonded to), feathers in three ways:

Firstly, ingested Pb (from the diet, drinking, preening and inhalation) is sequestered in the feathers during the moult. The content of a given feather may therefore reflect the internal Pb burden at the time it was growing and supplied from the blood stream (Burger 1993). The ability of birds to remove heavy metals from the blood and soft tissues during the moult is an important mechanism to reduce contaminant loads (Burger 1993).

Secondly, ingested Pb may be incorporated in the uropygial (preen gland) secretions and applied to the feathers during preening. One controlled experiment using zebra finches in a lead-free laboratory environment indicated that about two-thirds of the ingested Pb was sequestered within the feathers during the moult and the balance was from the uropygial gland (Dauwe *et al.* 2002). (This experiment was done by comparing Pb levels in the equivalent regrown and not regrown feathers in a treatment group ingesting Pb through their drinking water). A field experiment on blackbirds provided a similar estimate of this ratio (Scheifler *et al.* 2006).

In situations where the lead in bird feathers is mainly from ingested sources, there is a strong correlation between the concentrations in feathers and those of other tissues such as blood, liver and bone (Burger 1993, Dong-Ha Nam *et al.* 2004) but this will not be the case where the dominant source of Pb contamination is external.

The order of concentration for Pb in house sparrows from a mildly contaminated urban environment was Liver<Bone<Feathers<Lung<Stomach<Brain<Heart<Muscle – indicating that feathers would be a useful, non-destructive indicator of endogenous contamination (Swaileh & Sansur 2006). However, it has become clear that bird feathers are also capable of collecting and retaining Pb particulates from the external environment through contact with contaminated air, water, soil, vegetation and other surfaces (Dauwe *et al.* 2003, Dong-Ha Nam *et al.* 2004, Scheifler *et al.* 2006, Hahn *et al.* 1993). This third pathway for Pb contamination might be expected to dominate in the early aftermath of a fugitive dust incident with an increasing probability of bio-accumulation through food ingestion and preening over time. Bio-accumulation, if it occurred, might be expected to manifest itself in declining bird health and condition, reproductive failure and a failure of local populations to recover (Burger 1993).

The interpretation of Pb levels in bird feathers is complex as both endogenous and exogenous pathways are involved and their relative importance may change over time. Knowing the pathways is of considerable importance in understanding the ecological and public health risks inferred from using the birds as indicators.

The sampling strategy used in this pilot study was directed at minimising the exogenous pathway by choosing a feather that would have probably been replaced within 2-4 months of sampling and from a position that was not highly exposed to contact with external surfaces. The feather samples were also washed with acetone and deionized water to remove any metals that were not tightly bound to the feather structure.

NICKEL (Ni) IN BIRDS & FEATHERS

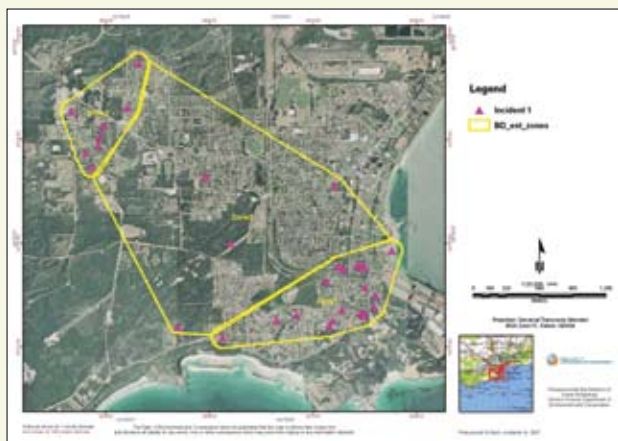
Unlike Pb (which has no biological function and is universally a toxicant), nickel is a trace element that occurs naturally in biological tissues. It is however toxic to plants and animals at high concentrations. Nickel has been found in bird feathers probably from a combination of endogenous and exogenous sources but its metabolism and patterns of sequestration have not been well studied in birds (Eisler 1998).

Methods

SAMPLING BIRD FEATHERS

Following the fugitive Pb dust events that were recorded between December 2006 and March 2007, the Western Australian Department of Environment and Conservation mapped the distribution of bird mortalities and identified three 'impact' zones within the Esperance townsite (Figure 1). The highest bird mortalities occurred in the Dempster Head / West Beach area (zone 1) and in the Sinclair/ Nulsen area (zone 2).

Figure 1: Map of Esperance showing the tree lead dust impact zones.



Between 8 and 14 October 2007, approximately seven months after the last reported Pb dusting event, passerine birds were mist-netted at four sites around Esperance – two 'impact sites' and two 'reference' sites. The reference sites were selected because they lay well outside the known distribution of bird mortalities. These were at Bandy Grove, 5.25 km east of the port, and Woody Island, 14.5 km southeast of the port. The impact sites were at Panorama Street / Dempster Head Water Reserve, 300–400 metres west of the loading berths, and at the Cemetery Reserve in Nulsen, 3.1 km north-west of the Port.

Sampling was repeated on 4 and 13 October 2008, 19 months after the last reported Pb dusting event. A second impact site was utilised in zone 1 adjacent to the Rotary Lookout, 930 metres west of the loading berths. The impact site at the Cemetery Reserve was not re-sampled due to a lack of suitable mist-netting positions. The reference site at Bandy Grove had changed ownership and was no longer available. Woody Island was re-sampled as a reference site in 2008.

It was not possible to closely match vegetation types between impact and reference sites but the heath and thicket habitats utilised would normally all be occupied by the common coastal honeyeaters and insectivores of the region.

The Pb poisoning events occurred over the summer of 2006/07 and both impact areas were reported by local residents to be devoid of birds for some months thereafter.

Honeyeaters in particular were expected to be scarce given the high mortality observed in this group. The birds occupying the impact areas were expected to be a mixture of survivors from the dusting events and recruits (immigrants) from surrounding areas.

It was assumed at the outset that most birds would have moulted over the autumn/winter period and would be in 'fresh' plumage during the sampling period in spring (ie. during the breeding season). Silvereyes captured on Woody Island in early February 2008 were completing their primary moult (mean moult score 79.47%, s.d.= 17.3) indicating that the sampled feathers were actually replaced after breeding in mid to late summer. Therefore mid-primary feathers sampled in October would reflect the endogenous burden in the previous summer and / or the exogenous accumulation over a period of about 8 months, from about January to September.

The sixth primary was extracted from both left and right wings. Only one in each feather pair was used in the 2007 analysis but both were required in pooled samples in 2008. Primary 6 was selected because:

1. It was easy to locate and replicate during sampling;
2. It would probably have been replaced late in the basic moult;
3. Its near-central, and partially occluded, position in the wing would reduce contact with exogenous sources of metal contaminants relative to outer primaries or tail feathers; and
4. Its removal was unlikely to significantly impair the flight capability and fitness of the bird.

The feathers from each bird were packaged separately in press-seal plastic (food-storage) envelopes. The bags were labeled on the outside using a waterproof marker pen. The feathers were not exposed to the external environment until laboratory preparation.

In October 2008 New Holland honeyeaters, silvereyes and white-browed scrubwrens were banded with uniquely numbered metal rings issued by the Australian Bird & Bat Banding Scheme. The recapture of these birds may provide information on residency and trends in metal contamination, health and survival in individuals.

SAMPLE PREPARATION

The whole feathers were washed consecutively in de-ionized water (Milli Q, Ultrapore USA) and acetone, using an ultrasonic bath at each wash for three minutes. All glassware and storage containers were rinsed with 10% nitric acid prior to use. The sample was then dried at 60 °C and weighed.

CHEMICAL ANALYSIS

Samples were microwave digested in nitric acid. Concentrations of Pb and Ni were then measured by inductively coupled plasma-mass spectrometer (ICP-MS). The chemical analysis was conducted using NATA accredited methodology by the Chemistry Centre of Western Australia.

Results

BIRD CAPTURES

Sixty-two birds from seven species were captured at the four sites in October 2007.

Capture rates were 0.71 / net-hour at Bandy Grove, 1.67/ net-hour at Woody Island and 2.6 / net-hour at Panorama Street, but only 0.22 / net-hour at the Cemetery Reserve.

Ninety birds from 11 species were captured at the three sampling sites utilised in October 2008. The total capture rate in zone 1 (Panorama St - Rotary Lookout) increased from 2.6 / net hour in 2007 to 4.6 in 2008. The major contributor was an increase in New Holland honeyeaters from 0.2 to 1.54 / net hour. Silveryeye capture rates between years were similar ranging from 2.0 / net hour in 2007 to 1.92 in 2008. The number of scrubwrens may have increased slightly with a capture rate of 0.33 / net hour in 2007 and 0.69 / net hour in 2008.

On Woody Island total bird capture rate was higher in 2008 running at 2.5 / net hour but this probably reflects better catching conditions.

New Holland honeyeaters dominated the catch at both reference sites in 2007 (and in both years on Woody Island) were scarce at Panorama Street and absent from the Cemetery Reserve in 2007. This probably reflected the high mortality in honeyeaters between December and February 2006/07. New Holland honeyeaters were relatively abundant in October 2008 reflecting a probable recovery in the population by the second spring.

Silveryeyes were present at all sites and quite abundant at the Panorama Street impact site in October 2007. They were of similar abundance in that area during October 2008, indicating that either the dusting incident had less impact on silveryeyes, or that this dispersive species was much quicker to recolonize the impact areas than the honeyeaters. White-browed scrubwrens do not naturally occur on Woody Island and were absent from the Cemetery Reserve. Five were captured on the Water Reserve adjacent to Panorama Street in 2007 and nine in 2008. The number of scrubwrens in the zone 1 impact area may have increased slightly between October 2007 and 2008.

All feather-sampled species have been utilised in the 2007 analysis except a fan-tailed cuckoo captured at the Cemetery

Reserve. This is a migrant species and probably a very recent arrival at that impact site.

In 2008 feathers samples were collected from 27 New Holland honeyeaters, 18 silveryeyes and 8 scrubwrens. Feathers collected from other bird species were not utilised in the most recent round of metals analysis.

Samples were only taken from adult birds based on plumage, gape or vocal characters. All birds handled on the mainland in October in both years had unworn plumage and were not in moult. There was one moulting New Holland honeyeater in the sample on Woody Island.

In 2007 New Holland honeyeaters had young at the fledgling stage at both the reference sites. The species was scarce on Dempster Head (zone 1 impact site), where it was reported to have been common prior to the fugitive dust incidents. New Holland honeyeaters were also absent from the Cemetery Reserve impact site, which was remarkably devoid of small birds. Some western silveryeyes were nesting on Dempster Head (ie. birds had brood-patches) during the sampling period.

About 40% of silveryeyes captured in the zone 1 impact area in 2008 had defeathered brood-patches indicating current or recent incubation. Two fledgling New Holland Honeyeaters were also captured in the area indicating the resumption in breeding activity.

LEAD & NICKEL IN FEATHERS IN 2007

A spread of 25 samples were analysed initially to determine if there was any evidence of high Pb or Ni levels, or of contrasts between reference and control sites. As both high levels and an apparent trend were apparent in these results, a further 25 samples were prepared for analysis. These were selected to maximize the opportunities for statistical treatment.

Table 1 below presents the mean and range of Pb and Ni concentrations (mg/kg dry weight) recorded for each species at each site (reference and impact). Sample sizes by species and site are also provided.

Sampling Site	Species	N	Mean Pb	Range Pb	Mean Ni	Range Ni
Bandy Grove – Reference Site	Western Silveryeye	3	3.53	2.8-4.2	1.03	0.9-1.3
	New Holland Honeyeater	10	2.77	1.6-4.6	0.81	0.4-1.4
	White-browed Scrubwren	1	3.30	–	3.80	–
	Red Wattlebird	1	1.4	-	<0.5	-
Woody Island – Reference Site	Silveryeye	6	3.61	0.81-5.1	1.23	0.9-2.5
	New Holland Honeyeater	6	2.96	0.19-13	1.05	0.3 – 3.5
Panorama Street – Impact Site	Silveryeye	10	45.7	21-83	4.73	1.2-14.0
	New Holland Honeyeater	3	57.0	34-74	9.60	7.5-13.0
	White-browed Scrubwren	5	293.0	26-730	9.48	1.7-20.0
	Western Spinebill	1	170.0	–	4.4	–
Cemetery Reserve – Impact Site	Silveryeye	2	33.5	18-49	1.4	0.9-1.9
	Yellow-throated Miner	1	44.0	–	<0.5	–
	Fan-tailed Cuckoo	1	1.1	–	<0.5	–

In order to average Ni values, results reported by CCWA as <0.5 have been assigned 0.4, <1 assigned 0.9 and <2 assigned 1.9.



COMPARISON OF REFERENCE & IMPACT SITES IN 2007

High to extremely high Pb levels were recorded in all birds captured at the two impact sites in October 2007 (with the exception of the migratory fan-tailed cuckoo in which levels were comparable to those of birds from the reference sites). There was no overlap in the range of values between reference and impact sites. Mean values were between one and two orders of magnitude greater in impact sites than at the reference sites. The results for white-browed scrubwren at the Panorama Street (impact site) were bi-modal with two birds ranging 26-29 mg/kg and three individuals ranging 250-730 mg/kg. A western spinebill (a resident, territorial honeyeater species) also had an extreme feather Pb loading of 170 mg/kg.

Variances both within impact sites, and between reference and impact sites, were large, negating the use of parametric statistics. The small sample sizes possible from depleted impact site areas also limited opportunities for statistical treatment. Sample sizes were adequate for silvereyes, grouping captures from both impact and both reference sites. Grouped 'honeyeaters' (New Holland honeyeater, western spinebill, red-wattlebird & yellow-throated miner) could also be compared between aggregated reference and aggregated impact sites. The functional grouping of the honeyeater species was justifiable given the differential impact the dusting events had on these birds.

The Pb concentrations in silvereye feathers were significantly higher in the impact sites compared to the reference sites (Mann-Whitney $U=0$, $p<0.001$). Similarly the honeyeaters at impact sites had feather lead concentrations significantly higher than at reference sites (Mann-Whitney $U=0$, $p<0.001$).

Feather Ni levels from impact sites (at least from Panorama Street) were also significantly higher than at the reference sites in both silvereyes (Mann-Whitney $U=13$, $P<0.01$) and honeyeaters ($U=13$, $P<0.01$). High Pb and Ni characterised bird feathers from Dempster Head (Panorama Street). Relatively high combined Pb and Ni values were associated with two birds from reference sites. A white-browed scrubwren from Bandy Grove (Pb 3.3, Ni 3.8) and a New Holland honeyeater from Woody Island (Pb 13.0, Ni 3.5). This suggests that some birds captured in the reference sites may have moved from more contaminated areas and that the reference sites were not entirely representative of uncontaminated background levels.

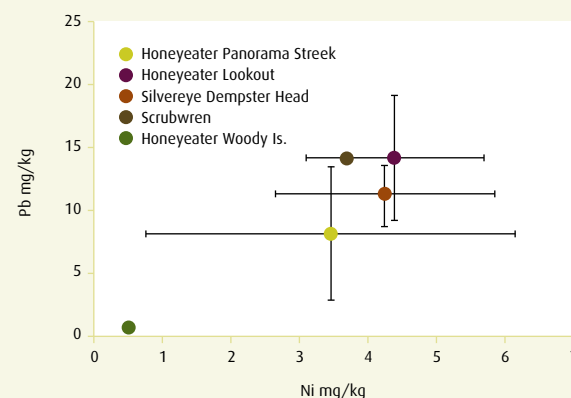
LEAD AND NICKEL IN FEATHERS IN 2008

RESULTS FROM POOLED SAMPLES

The initial results from the 2008 sampling indicated that the sample weight of a single primary feather was now insufficient to service the analytical detection limits. Pb levels were given at $< 2\text{mg/kg}$ in 19 New Holland honeyeater samples and $< 4\text{mg/kg}$ in 14 silvereye and 8 white-browed scrubwren samples. Such data were not comparable with the 2007 results or amenable to statistical analysis.

To overcome this problem the B feathers from individuals (P6 from the opposite wing) were randomly pooled to produce composite samples. The feathers from three New Holland honeyeaters, six silvereyes or eight scrubwrens were required to provide an acceptable sample weight. These amalgamations produced six New Holland honeyeater composite samples from impact areas, three New Holland honeyeater samples from the reference area (Woody Island), three silvereye samples from impact areas and one scrubwren sample from the impact areas. The mean concentrations of Pb and Ni from the pooled samples at each sampling site are plotted as a scattergram in Figure 2 (error bars are standard deviations).

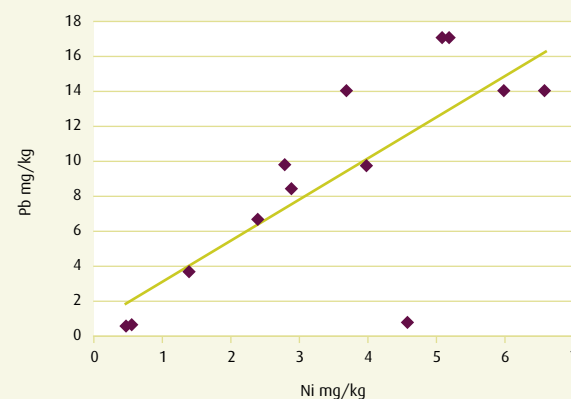
Figure 2: Mean feather lead levels in picked samples of bush birds from impact areas and reference



All the samples from the zone 1 impact area have significantly elevated concentrations of both metals compared with the New Holland honeyeater sample from the Woody Island reference site. There is considerable variation within impact site samples for both metals indicating that these differences are unlikely to be significant.

Figure 3 plots the feather Pb concentrations against Ni concentrations in each individual pooled sample.

Figure 3: The relationship between lead and nickel concentrations on the feathers of Esperance birds



There was a very strong correlation between the levels of Ni and Pb contamination in the bird feathers ($r = 0.7608$, $p < 0.005$). The observation that current Ni contamination remains an effective predictor of former Pb contamination indicates that the two contaminants had a common source and are dispersed in a similar way. Note that one pooled sample from the Woody Island reference site with a low Pb concentration had a relatively high nickel concentrations. This probably indicates that one or more birds in this pool had some recent contact with an impacted area on the mainland.

DIFFERENCES IN Pb & Ni CONCENTRATIONS BETWEEN REFERENCE & IMPACT SITES.

In 2008 New Holland honeyeater samples from the zone 1 impact sites had feather Pb concentrations of between 3.7 and 17 mg/kg compared with 0.61- 0.81 mg/kg at the Woody Island reference site, on average 16 times background. The reference and impact site medians were significantly different (Mann-Whitney $U = 0$, $p < 0.025$).

In 2007 the New Holland honeyeaters in the zone 1 impact area had feathers 19.25 times more contaminated with Pb than on Woody Island. It should be noted however that some birds captured on Woody Island had slightly elevated Pb and Ni levels presumably from contact with impacted mainland habitats outside the breeding season. The 'benchmark' Pb level in New Holland Honeyeaters on Woody Island also declined from a mean of 2.96 mg/kg in 2007 to 0.7mg/kg in 2008. Based on the 2007 benchmark New Holland honeyeaters in the zone 1 impact area had feather Pb levels only 3.8 times background in 2008.

In 2008 Ni concentration in the zone 1 impact area were approximately 4 times those at the Woody Island reference site (excluding 1 pooled sample with a bird or birds that had probably moved through a mainland impact area).

DIFFERENCES IN Pb & Ni CONCENTRATIONS AT IMPACT SITES BETWEEN 2007 & 2008.

Mean New Holland honeyeater feather Pb contamination levels at the zone 1 impact sites in 2008 were 11.33 mg/kg, this was 19.8% of 2007 levels for combined honeyeaters. This decline was statistically significant (Mann-Whitney $U=0$, $p<0.01$).

A similar decline in Pb loading occurred in silvereyes. In 2008 silvereye feathers had Pb concentrations of between 9.7 & 14 mg/kg (mean 11.2) about 25% of the 2007 level of 57 mg/kg. In the scrubwrens the Pb levels in the zone 1 impact area dropped to 14 mg/kg in the 2008 composite sample compared with a 2007 mean of 293 mg/kg.

There was a significant decline in Pb levels between 2007 and 2008 when the results for all samples (3 species) in the impact areas were combined (Mann-Whitney $U=31$, $p<0.001$).

In 2008 the mean Ni concentrations on the feathers of birds in the zone 1 impact area were similar for all three species ranging from 3.2 to 4.3 mg/kg. These were lower than those recorded in 2007 but the decline was not as marked as that observed in Pb.

COMPARISON BETWEEN BIRD SPECIES

Figure 4 shows the mean Pb concentrations in the feathers of the three common indicator species in 2007 and 2008 at the reference site (Woody Island) and in the zone 1 impact site (Dempster Head). Note that the results from 2007 are the means from individual birds whilst those from 2008 are based on the means of pooled samples.

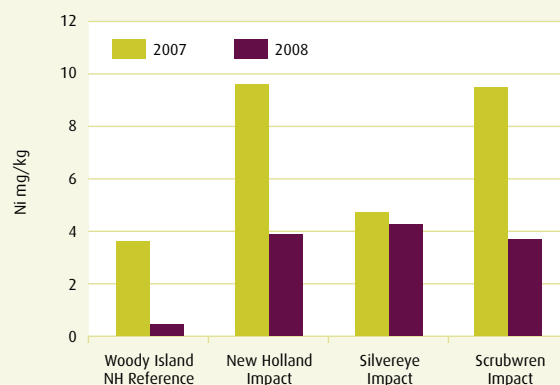
Figure 4: Lead concentrations in the feathers of sampled bird species in 2007 and 2008.



In 2007 there was a marked difference in the concentrations recorded in the three bird species in the impact areas. However, in 2008 the levels recorded were remarkably uniform across these species. This trend supports the hypothesis that the variations observed in 2007 were the result of differences in residency time since the dusting event. The scrubwrens were probably not affected by Pb poisoning and have been present in the impact area continuously accumulating Pb on their feathers since the annual basic moult. The small number of New Holland honeyeaters captured in 2007 probably represented early re-colonisers along with the more abundant silvereyes. As such these species would have had a lower exposure time than the scrubwrens.

Figure 5 shows a similar pattern of exposure for nickel dust exposure although the decline in feather nickel levels is less marked in the silvereyes. The silvereyes forage in a diverse number of micro-habitats and may be more exposed to ongoing nickel dust emissions.

Figure 5: Nickel concentrations in the feathers of sampled bird species in 2007 and 2008.





Discussion

EXTENT & PATHWAYS OF CONTAMINATION

Feather Pb levels have been reported from a range of environments that were, to varying degrees, contaminated but not always associated with any obvious reduction in bird health or condition. Different feathers have different exposure patterns to both sequestered and exogenous Pb so direct comparison between studies should be treated with some caution.

The feathers of palm doves in two relatively contaminated Saudi cities had means of 21.07 and 16.63 mg/kg respectively whilst in a relatively uncontaminated location the value was 1.19 mg/kg (Mansour 2004). Urban blackbirds in France were reported to have feather Pb concentrations around 7.75 mg/kg (Scheifler *et al.* 2006). Urban house sparrows on the West Bank (Palestine) had feather Pb levels between 4.6 and 11.1 mg/kg (Swaileh & Sansur 2006). The maximum Pb level recorded in apparently healthy individuals across a comprehensive range of seabird genera was 25.8 mg/kg (in some gulls) however albatrosses with levels above 40 mg/kg showed evidence of poisoning (Burger & Gochfeld 2002).

In 2007 most Esperance bush birds in the impact area had feather Pb levels well in excess of the extremes recorded in

other studies around the world. By October 2008 the feather levels had declined significantly although still well above background.

Given that Burger & Gochfeld (2002) considered that feather Pb concentrations as low as 4 mg/kg were potentially associated with adverse and toxic effects, it seems unlikely that the levels recorded in Esperance reflect the internal Pb burden of the birds sampled. Internal concentrations at these levels would almost certainly be lethal, as it was at the time of the dusting events. The most probable explanation is that the majority of the Pb in the feathers collected in October 2007 was not sequestered within the internal structure of the feathers but had been collected exogenously from an environment still heavily coated with invisible lead carbonate dust.

To examine this further, in the 2008 sampling, 10 silvereyes from the zone 1 impact area were euthanised to compare liver tissue concentrations with the levels in the feathers (Gerard Smith pers.comm.). All these birds were apparently healthy at capture and no evidence of clinical changes attributed to heavy metals were detected from the autopsies. The sample weights for both feather and liver samples were below that necessary to get precise Pb levels. All the feathers were reported at < 4.0 mg/kg and livers < 2.0 mg/kg. A pooled sample using the B feathers collected from these silvereyes produced a more elevated result of 9.8 mg/kg. These results

support the contention that high feather Pb levels were not correlated with a high internal Pb burden. This is consistent with the observation that high feather Pb concentrations did not appear to be associated with bird morbidity or mortality in October 2007 or 2008.

The experience with lead carbonate dust suggests that, once settled, it binds strongly with inorganic and organic surfaces, including plant leaves and bird feathers. Feather keratin appears to have a particularly strong affinity for this material and is capable of sweeping it off soil, rock and foliage. It binds so strongly with feathers that little can be removed with acetone treatment before chemical analysis. The birds themselves do not appear to remove and ingest it during preening despite contact between the plumage and the moist tongue / gape in the process.

Lead carbonate dust was also evidently not being absorbed through the digestion of insect food. Ants (*Iridomyrmex conifer*) sampled from the zone 1 impact area in October 2008 had Pb concentrations reported at < 1.3 mg/kg whilst *Iridomyrmex purpureus* and *Myrmecia* sp on Woody Island had lower concentrations between 0.06 & 0.37 mg/kg. This suggests that some additional Pb may have been ingested with the insect diet of the bush birds in zone 1. This Pb was apparently not being absorbed into the blood-stream in sufficient quantities to cause ill effects.

Nickel concentrations in mallard primary feathers ranged from 2.0 -12.5 mg/kg within 20-30 km of a Canadian nickel smelter compared 0 – 0.4 mg/kg at a reference site. At other Canadian contaminated sites nickel in black duck primaries ranged from 2.5 -3.7 mg/kg verses 0.2-1.5 at other sites. Ruffed grouse at contaminated sites average 7.3 mg/kg in the primaries of birds from contaminated areas verses 2.9 at uncontaminated ones (Eisler 1998). Depending on bird species the mean nickel levels in bush bird primaries on the impact areas ranged from 4.4 to 9.6 mg/kg in 2007, with an upper extreme at 20 mg/kg. At the reference sites in 2007 mean nickel levels in the bird feathers ranged from <0.5 – 3.8 mg / kg. The birds captured in the zone 1 impact area in 2007 had the highest nickel concentrations recorded in reported studies of metal accumulation in bird feathers. Nickel is a necessary trace element and may not be preferentially sequestered in feathers in the same way as highly toxic heavy metals such cadmium, mercury and lead (Eisler 1998).

Conclusion

By October 2008, approximately 19 months after the last reported major lead carbonate dust incident, Pb concentrations on bird feathers in impact areas had declined significantly. However Pb levels in the environment were still estimated at 10 to 15 times background.

The bird mortality events that occurred between December 2006 and March 2007 appear to be associated with a period when lead carbonate dust was in the air and settling on flowers. The predominance of nectar-feeding species amongst the casualties suggests that dust suspended or dissolved in nectar may have been the principle mechanism for ingestion and absorption. The aspiration of airborne dust is a second potential pathway capable of producing Pb intoxication, although this might be expected to have affected a wider range of species.

In October 2007 the zone 1 impact area was apparently depleted in birds. The locally abundant New Holland honeyeater was particularly scarce. This partial nectar-feeding species was reported to have suffered high mortality during the period of the fugitive dust events and probably took longer to re-colonise zone 1 than the silvereye. By the second spring (October 2008) the New Holland honeyeater population had apparently made a significant recovery at the zone 1 sampling sites.

The Bush Canaries project was designed to use birds and their feathers to monitor the extent and persistence of Pb contamination in the Esperance environment. During the first two sampling periods in October 2007 and 2008 high concentrations of Pb were detected in / on the feathers of the sampled species. It became apparent that this contamination was 'ectopic' rather than internally sequestered and this manifested in a lack of observations of longer-term impacts on bird health. The surprisingly low vulnerability of the birds to the high environmental Pb loading is attributed to the apparent capacity of lead carbonate dust to bind strongly to surfaces (including feathers).

The decline in Pb contamination in bird feathers between 2007 and 2008 tracks the process of dilution and the gradual movement of lead carbonate dust from the above ground environment and vegetation to the soil profile. If there is uniform dilution then this material will eventually cease to pose an environmental risk. However physical and biological sorting processes may result in the concentration of Pb in some areas of soil. If this occurs Pb may be taken up by plants and enter the natural food-chain. Monitoring should continue until natural dilution leads to bird feather contamination levels that are not significantly different from background.

Acknowledgements

This project was supported by the Conservation Council of WA and by volunteers from Esperance LEAF and Locals for Esperance Development (LED). LEAF funded the chemical analysis conducted by the Chemistry Centre of Western Australia. The Department of Environment and Conservation granted permission to carry out the bird sampling and the Shire of Esperance and Water Corporation (Esperance) authorised access to their reserves.



CHARLES DARWIN RESERVE CLIMATE CHANGE OBSERVATORY MONITORING PROGRAM PLAN

BACKGROUND

THE PROBLEM

A scientific review and workshop facilitated by the Conservation Council of WA (CCWA) in June 2008 confirmed that structured, long term observations on biological responses to climate change in Western Australian terrestrial ecosystems were very limited. Such observations were however essential in underpinning any climate change adaptation strategy for biodiversity conservation and for the validation of model-based approaches.

THE OBSERVATORY CONCEPT

One approach to dealing with this deficiency is to adopt the 'observatory concept', ie. to concentrate research / monitoring effort into strategically significant locations for long periods of time. In order to investigate biodiversity responses to climate change it is also important that the natural habitats are managed to reduce, as far as possible, other anthropogenic

stresses on plants and animals, such as competition or predation from introduced species. Charles Darwin Reserve (formerly White Wells Station) is owned and managed by Bush Heritage Australia to protect the biodiversity of habitats that were heavily impacted by the clearing of the Western Australian wheatbelt. It covers 68 000 hectares and encompasses part of one of the largest areas of native vegetation remaining in its bioregion.

To monitor the incipient changes in terrestrial plant and animal populations and ecosystems as a result of climate change it is strategically sound to focus on the sharp transition zones. Charles Darwin Reserve (CDR) straddles the mulga-eucalypt line between the wheatbelt (Avon) and arid (Yalgoo) region on the north-eastern boundary of the south-western Australian biodiversity hotspot. It is one of the most dramatic transition zones in WA and is an area universally predicted to rapidly become warmer and drier in current climate models. CDR is also only four hours from Perth, an important logistical and cost consideration.

Management objectives

The management objectives pertaining to the CDR Climate Change Observatory (the Observatory) operate at several levels, those of the State, of Bush Heritage Australia and the Observatory Project.

On the broad scale, state natural resource and biodiversity conservation managers require information on the biological responses to climate change to guide adaptation strategies and to validate model-based approaches.

Bush Heritage Australia purchased White Wells Station (now Charles Darwin Reserve) primarily to protect the biodiversity of woodland habitats that have been extensively lost to clearing over most of the Avon (wheatbelt bioregion). These habitats are on the frontier of their distribution on CDR and are now threatened by climate change.

Within these contexts the overarching objective of the Observatory project is to *'detect incipient biological responses to changes in climate variables to inform adaptation strategies for biodiversity conservation both on a bioregional scale and within the Charles Darwin Reserve itself'*.



Location map for the Charles Darwin Reserve

The more detailed aspects of the objective are encapsulated in the construction of the individual indicators set out in the table below. The table also summarises the description of ecological models, indicators, sampling design and metrics

Indicator construction

Since November 2006 CCWA citizen scientists have been surveying the biodiversity of key habitats on CDR. Attention has focused on three CDR monitoring sites in wheatbelt Salmon Gum / Gimlet Woodlands (CDR 31, 33 & 46), which are at their distributional limits in the southern half on the

reserve and two sites in Mulga (*Acacia*) shrublands (CDR 80 & 84) which are at their distributional limits at the northern end. However ecological relationships spanning other habitats have also been investigated.

The results of this survey / surveillance phase have been used to identify and evaluate appropriate subjects to monitor a variety of predicted biological / ecological responses to climate change. A composite set of 10 biological indicators have now been constructed for long-term monitoring. The logic used to construct these indicators is summarised in the table below.

INDICATOR CONSTRUCTION TABLE

Ecological Model	Taxa / Community/ Functional Group	Metrics	Indicator
Increasing minimum temperature, declining rainfall and an increasing proportion of summer rainfall will have implications for the survival, reproductive performance and recruitment of woody plants favouring arid zone species.	Woody perennial plants at Salmon Gum/ Gimlet Woodland and Mulga study sites	Height, stem diameter, canopy density, flowering frequency, fruiting and seed set. Number of seedlings / area	1a - Change in growth rates, canopy health, survivorship, recruitment, species composition, flowering frequency, fruiting, seed set and recruitment in relation to climate variables (temperature, humidity, total rainfall and timing of rainfall).
Increasing minimum temperature, declining rainfall and an increasing proportion of summer rainfall, will produce different responses in C3 versus C4 plant species. It is expected C3 plants will be favoured by increasing atmospheric CO ₂ concentration but rising temperatures and increased proportion of summer rainfall will favour C4 grasses and chenopods.	All plant species at Salmon Gum/Gimlet Woodland and Mulga study sites.	Relative percentage cover / biomass of C3 and C4 plant species.	1b - Change in C4 / C3 biomass ratio over time related to climate variables.
Ant communities spanning the mulga-eucalypt line are comprised of a range of arid zone, south-western and ubiquitous species. The species composition and structure of ant communities are likely to respond to shifts in habitat and food availability forced by changes in climate. Predicted increase in distribution and abundance of arid zone species and increased disturbance effects in community structure of south-western habitats.	Ant communities in Salmon Gum / Gimlet Woodland and Mulga study sites.	Species composition, species richness and dominance index of ant communities.	2a - Change in species composition, species richness and dominance index in relation to climate variables.
The carbon and nitrogen stable isotope signatures of ant chitin will reflect changes in the diet including changes in energy flow through C3 or C4 components of the vegetation or other producers (eg. cyanobacteria, algae in lichens or salt lakes).	Ant communities in 6 major vegetation types on CDR	Stable isotope ratios of carbon (delta C) and nitrogen (delta N) in worker ant chitin.	2b - Change in delta C and delta N in relation to climate variables.
Two species of mulga ants (that thatch their nest entrances with terete <i>Acacia</i> phyllodes) occur on CDR. <i>Polyrachis zimmerae</i> is an arid zone mulga species and <i>P. pyrrhus</i> occurs on the semi-arid north-eastern margin of the wheatbelt. Both occur in the arid zone Mulga /Bowgada scrub and Fine-leaf Jam dominated scrub heath on CDR. Possible hybrids occur south of the mulga-eucalypt line indicating possible invasion by <i>P. zimmerae</i> . The relative abundance and distribution of these species may change in response to increasingly arid conditions. The nests are distinctive and readily mapped.	<i>Polyrachis zimmerae</i> and <i>P.pyrrhus</i> nests	Mapped nest density and distribution at mulga monitoring site CDR 84	2c - Change in nest density and relative abundance in relation to climate variables at observatory monitoring sites. 2d - Distribution of <i>P. zimmerae</i> and <i>P. pyrrhus</i> nests on CDR.

Ecological Model	Taxa / Community / Functional Group	Metrics	Indicator
Seven (possibly eight) bat species have been captured or recorded on bat detectors on CDR. These include species with widespread distributions, a partial migrant and species on or near the edge of their distributions in either the arid or south-western regions (frontier populations). The high energetic cost of flight and the exposed skin of bat wings impose significant evolutionary constraints. As a consequence bats are particularly sensitive to changes in temperature, humidity and the seasonal distribution of invertebrate production. As such the composition and structure of bat communities are likely to be a useful indicator of climate change impacts.	The microbat community at CDR.	Number of constant frequency (CF) contacts recorded in standard fixed-station bat detector samples. At CDR Climate-Change Observatory study sites and other stations (eg. near watering points).	3a - Change in the presence - absence and/or frequency of bat species on CDR in relation to climate variables.
The White-striped Mastiff Bat (WSMB) cannot occupy regions where the average monthly minimum night temperature exceeds 20°C. CDR is currently occupied by breeding WSMB during the summer months as temperatures currently sit below this limit. Conversely WSMB appear to be absent from CDR during the winter months joining the northward migration. A relatively small increase in summer minimum temperatures would see this species go from a summer breeding species to a winter migrant at CDR.	White-striped Mastiff Bat <i>Austronomus australis</i> .	Presence / absence or frequency in standard bat detector samples.	3b - Presence and timing of foraging of White-striped Bats in relation to climate variables, particularly over-night minimum temperatures.
Some widely distributed microbats increase in size with decreasing temperature from north to south. These clinal trends are evident in two species captured at CDR, in Gould's Wattled Bat and the Lesser Long-eared Bat. As the region in which CDR is located increases in temperature (particularly in minimum temperatures) these two species should show character displacement towards a smaller size. Forearm length is currently closer to south-west populations than arid to zone ones.	Gould's Wattled Bat <i>Chalinolobus gouldii</i> and Lesser Long-eared Bat <i>Nyctophilus geoffroyi</i>	Forearm length (mm) and weight (g) from captured samples.	3c - Change in forearm length in relation to environmental variables, eg. mean minimum temperatures and humidity (potential evapo-transpiration).
Bat species occupy different habitats and ecological niches and these may shift in response to vegetation change (carbon or energy source) or the arrival extinction of other bat species (competitors) as a consequence of changing climate. Frontier populations such as that of the Western Broad-nosed Bat at CDR may specialise in foraging in certain (more arid?) habitats	All species in CDR microbat community	Delta C and Delta N of bat fur.	3d - Change in carbon source (from Delta C analysis) and or trophic level (from Delta N) in relation to changes in vegetation cover (eg. C4/C3 biomass ratio) or bat community structure forced by shifts in climate variables.
Three Dunnart species dominate the small ground vertebrate fauna on CDR. The Little Long-tailed Dunnart appears to be ubiquitous, Gilbert's Dunnart occupies south-west habitats including the Salmon Gum Woodlands whilst the Fat-tailed Dunnart occupies the arid mulga and salt lake habitats. The relative abundance and habitat selection of these marsupial mice may change in response to climate change induced habitat alteration. Gilbert's Dunnart would appear to be most at risk at CDR as its habitats would be most threatened by the predicted expansion of the arid zone.	Little Long-tailed Dunnart <i>Sminthopsis dolichura</i> , Gilbert's Dunnart <i>S. gilberti</i> and Fat-tailed Dunnart <i>Sminthopsis crassicaudata</i> .	Relative abundance and condition of Dunnarts captured at the 5 climate change observatory detailed study sites.	4 - Change in the relative abundance of Dunnart species in relation to vegetation change and climate variables.

Resources & partnerships

THE PEOPLE

The Charles Darwin Reserve Climate Change Observatory is a partnership between Bush Heritage Australia (BHA) and the Conservation Council of WA (CCWA) citizen science initiative.

CCWA is Western Australia's peak conservation body representing around 90 conservation groups. It plays an increasingly important role in linking on-ground action and community campaigns to the reform of government and industry environmental policy.

Bush Heritage Australia is a non-government, not for profit, organisation which has purchased and now manages a significant area of Australian land for biodiversity conservation. To do this, it employs a range of highly-skilled professional staff including ecologists and reserve managers.

The most important resource for the CDR Climate Change Observatory will be the association of citizen scientists who will collect, manage and analyse the data to service the indicators. This group will need to be a blend of people with relevant scientific expertise and enthusiastic conservation oriented volunteers and students. In the longer-term an ecotourism product based on the Observatory program will be developed. Such a product would assist with data collection and the financing of the monitoring program.

Given the long-term (circa 30 year) horizon envisaged for the Observatory program particular attention will need to be given to succession-planning within the evolving management structure. The initial Observatory management team was assembled through the survey / pilot project phase and consisted of six members.

Dr J.N. Dunlop – Coordinator, ecologist,

Dr Indre Asmussen – Vertebrate ecologist

Dr Elizabeth Rippey – Plant ecologist

Dr John Rippey – Assisting in plant ecology

Mr David Ball – Meteorologist

Dr Lynda Chambers, Bureau of Meteorology

Manager Charles Darwin Reserve – Reserve logistics

The Observatory Program has been designed to complement the Environmental Outcomes Monitoring (EOM) conducted on CDR by Bush Heritage Australia. There will also be the opportunity to exchange locally experienced people between the two programs. The first such exchange took place in August 2009.

The first five years of the Observatory Program will require relatively intensive sampling to extend the survey / pilot project work used to construct the indicators and establish a set of 'baseline' data series encompassing current inter-annual variation. Once the baseline is established there may not be a necessity for annual sampling to service the indicators. The interpretation of some of the selected indicators would be enhanced by research projects into various aspects of subject biology or ecology. The Observatory will encourage prospective Honours and PhD students to take up projects identified by the management team. Members of the team have adjunct or other relationships with Western Australian Universities.

DATA MANAGEMENT

The development of an effective data-base management system will be central to the Observatory functions which rely on the continuity of the indicator time series. It is also essential that the Observatory data (and reporting) are accessible to other stakeholders.

The most efficient and useful solution may be to establish a web-based environmental data portal for the region that encompasses the three adjoining conservation stations CDR, Mt Gibson and Ninghan and the adjacent uncleared unallocated crown land. This non-government, 'conservation stations' region also encompasses two major mining operations (Extension Hill & Mt Gibson Gold) with environmental data acquired as part of the environmental assessment process, the development of threatened flora recovery plans and from ongoing monitoring requirements (eg. mine-site rehabilitation projects).

CDR has several programs collecting environmental / biodiversity data including the extensive EOM program, the Climate Change Observatory Program, the Edith Cowan University research program related to fire and York Gum conservation and the Wildflower Society, WA Museum and Earthwatch surveys. The Australian Wildlife Conservancy are acquiring a range of survey data sets for Mt Gibson Station. A common portal sharing information between all the managers would be an optimal arrangement. The mining companies might be invited to contribute to the cost of establishing the portal.

FINANCIAL RESOURCES

The Observatory will require money to retain a part-time CCWA coordinator, for travel and field expenses and to meet some laboratory analysis costs associated with the indicators. It is anticipated that over the early 'baseline' years these needs will be met from small grant funding to CCWA. In the medium term revenue from an ecotourism product, based on the Observatory's monitoring program, has been identified as a potential funding source.

Bush Heritage Australia has the capacity to accommodate Observatory monitoring teams and does so without charge. Observatory citizen-scientists will continue to make an in-kind contribution to the management of CDR.

Reporting

The frequency of reporting will depend on a number of factors including the rate of data acquisition, CDR management issues, CCWA requirements, joint project requirements (eg. servicing a common 'Conservation Stations' portal, funding-body acquittal requirements and the level of public demand. Ultimately the rate and method of reporting will be determined by the Management Team but initially might consist of an annual activity / progress report and a tri-annual technical monitoring report. Some of the material collected during the pilot will, with some additional sampling, be suitable for publication in the scientific literature.

Communications

The Observatory will need to communicate effectively with CCWA affiliates, Bush Heritage supporters, Commonwealth, State and Local Government agencies, scientific institutions, the neighbouring conservation and pastoral stations, the local mining industry and the public. It could do this as CCWA, BHA or jointly, as both NGOs have communications / media management capacity.

The communications strategy will depend on the audience and the message. Important initial communications will most probably involve marketing the Observatory concept with stakeholders and funding bodies. Communications with scientific institutions aimed at developing research partnerships may also be a priority, possibly by hosting seminars. In the longer term the messages may target the wider community about the observed impacts of climate change in the region or attempt to engage the agencies on the importance of the conservation stations in regional climate change adaptation strategies.

If developed the regional conservation stations web-portal would be an important continuous communications vehicle.

The results from some of the pilot projects will be submitted for publication in the scientific literature.

Pilot projects

During the survey / establishment phase between November 2006 and June 2009 CCWA citizen scientists have spent 35 days (approximately 140 participant days) carrying out preliminary work on CDR. This has involved multi-method vertebrate and invertebrate ground-fauna biological survey work at five detailed study sites, three in the Avon bioregion Salmon Gum-Gimlet woodlands and two in a southern outlier of arid *Acacia* (mulga) shrublands. A microbat survey was also conducted across the reserve using live capture and bat-detector techniques.

In August and October 2008 the Western Australian Wildflower Society made a systematic collection of flora from the reserve, lodging specimens of all taxa with the Western Australian Herbarium. A verified (scanned) field herbarium produced from this survey will be utilised for all vegetation monitoring on the reserve, including the identification of

indicator plant species by citizen scientists working with the Observatory.

In January 2009 the Observatory's automatic weather station was installed and the calibration work has now been completed. The station measures barometric pressure, temperature, humidity, solar radiation, wind-speed and direction every 10 minutes. Two different electronic rain-gauges are being evaluated against the homestead gauge which has been certified by the Bureau of Meteorology.

The early survey trips to CDR coincided with the final two years of a protracted drought in the region and the densities of small vertebrate ground fauna were very low at the Observatory study sites. The abundance of small vertebrates increased in 2008 / 09 following an average year with both winter and summer rain. Only 11 reptile species were recorded within the study sites during the survey and all were represented by a low number of captures. Dunnarts (*Sminthopsis* spp) dominated the small vertebrate ground fauna in all seasons becoming relatively abundant in 2008 /09. Gilbert's Dunnart *Sminthopsis gilberti*, one of three species identified, was only captured in winter outside the normal survey periods in spring and autumn.

Seven species of microbats were identified during the survey period.

As expected ants dominated the invertebrate ground-fauna with at least 22 species identified in the two habitats represented in the study sites.

Standard bush-bird census techniques are being utilised by Bush Heritage staff at some 90 CDR monitoring sites to evaluate the effectiveness of reserve management strategies. The Observatory project has not pursued the use of birds as indicators to avoid any duplication of effort.

Pilot investigations covered all the selected indicators except those related to plant ecology (Indicator 1).

ANT COMMUNITY STRUCTURE AS AN INDICATOR (INDICATOR 2A)

Australian ant communities have a distinctive functional group structure that responds in a predictable way to ecological disturbance or recovery, an attribute which has lead to their widespread use in monitoring programs (eg. Andersen 1991, 1993 & 1995, Majer & Nicholls 1998). Foraging workers of the genus *Iridomyrmex* control the soil surface and vegetation and the other ant species in the assemblage are adapted to avoid direct interactions with these dominant ants. This is achieved in variety of ways such as having separate activity periods, cryptic foraging, morphological or olfactory mimicry, spatial avoidance, solitary foraging and heavy armour.

Within undisturbed habitats ant communities will have a characteristic species richness, balance of functional groups and apportionment of individuals between the dominant ants and the rest of the assemblage. In disturbed habitats the relationships between the dominant ants and the rest of the assemblage change. Regenerating habitats frequently have more species as the dominant ants have not established the numbers to assert control and the assemblage may include opportunistic species that will disappear later (ie. they will have higher species richness & low dominance). In habitats with lower level, persistent disturbance (eg. grazing pressure) there may also be some increase in species richness as the pressure on the resident ants provides openings for opportunists. A reduction in the abundance of sensitive



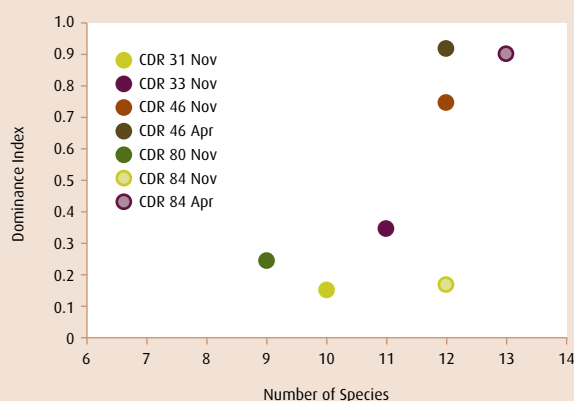
The CDR Climate Change Observatory meteorological station.

resident species due to the pressure or stress may also expand the resources available to the dominant *Iridomyrmex* leading to an increase in their abundance (higher species richness, higher dominance).

Ant communities were sampled using pitfall traps at each of the Observatory study sites during the survey phase. The data were analysed to confirm that measures of ant community structure could be utilised to detect disturbance, including the impacts of climatic perturbations such as high temperatures, drought or flooding.

In Figure 1 ant species richness (ie. the number of species) has been plotted against a dominance index for sample taken in the Salmon Gum / Gimlet woodland and Acacia (Mulga) shrubland study sites. The Dominance Index is $c = \sum (n_i / N)^2$ where c is the Dominance Index, n_i is the number of ants captured for each species and N is the total number of ants captured.

Figure 1: Species richness verses dominance index in the ant communities sampled.



Salmon Gum / Gimlet sites CDR 31 & 33 are located in a grazing shadow and have soil condition characteristics that indicate little historical grazing impact. However the Salmon Gum woodland at CDR 46 is within the area of historical (pre-2003) grazing activity and shows some signs of soil deflation, reduced infiltration and a lack of cryptogams. Both undisturbed sites had low dominance index. CDR 46 was sampled twice and both occasions had a slightly higher species richness and much higher dominance index when compared to the undisturbed sites

The *Acacia* (Mulga) shrubland sites had species richness and dominance index values in the same range as the undisturbed Salmon Gum / Gimlet sites when sampled in November 2006. Site CDR 84 was re-sampled in April 2009 and on this occasion an increase in species richness and the dominance index indicated significant disturbance. CDR 84 is on outwash plain that flooded with sheet flow in a heavy rainfall event during February 2008. None of the other study sites showed evidence of flooding. It is likely the ant community at CDR 84 was still recovering from that sheet flow event in April 2009. Increased surface flooding due to a lack of infiltration might also be the proximate cause of disturbance to the ant community at CDR 46.

The pilot investigation into ant community structure indicates that it should be a reliable indicator of disturbance in the monitored habitats at CDR. Interactions between ant community structure, grazing history, soil condition, rainfall intensity and flood events may already be emerging.

ANT SPECIES AS INDICATORS (INDICATOR 2B)

Mulga Ants (the *Campomyrma* group of the genus *Polyrachis* – Rudi Kohout pers.comm.) occupy the arid shrubland habitats of central Australia. They get the name from their distinctive habit of thatching the walls of their nest entrances with the narrow / terrete phyllodes of mulga and other similar *Acacias*. These ants typically occur in habitats receiving sheet flow and their nest entrances are raised or banded to protect the below ground chambers from flooding. Mulga ants are at, or close to, their distributional limits on CDR.

The pilot investigation has determined that there are two species of mulga ant on CDR, *Polyrachis zimmerae* and *Ppyrrhus* (Brian Heterick pers.comm.). There are thought to be as many as eight species in Australia with up to five undescribed species in the arid shrublands of Western Australia – Rudi Kahout pers.comm.). *Polyrachis pyrrhus* has previously been recorded from the edge of the wheatbelt east of Dalwallinu. The nearest recorded locality for *P.zimmerae* was Menzies in the Murchison Goldfields, well within the arid shrublands.

The nest entrances of the two species are quite distinctive which facilitates identification and mapping without the need to capture the ants or collect specimens.



Nest entrances of *Polyrachis pyrrhus* at CDR 84



Nest entrances of *Polyrachis zimmerae* at CDR 84.

Both species have been mapped at CDR 84 which is in arid grove and intergrove *Acacia* shrubland on an outwash plain. At this site *P. zimmerae* is dominant. The nests of both species are thatched with the phyllodes of *Acacia linophylla*.

At CDR both mulga ants penetrate south of the mulga – eucalypt line where they occur in Jam *Acacia acuminata* shrubland on lateritic sand and thatch their nests with Jam phyllodes. However, it has been observed that the mulga ants utilise open spaces (eg. the intergroves at CDR 84) and these are limited in the closed Jam shrublands. Most nests south of the mulga-eucalypt line are on the edge of tracks or in artificially cleared areas. The establishment of tracks may therefore be facilitating the southward spread of mulga ants.



Polyrachis pyrrhus nest on the edge of a track in Jam shrubland.

The arid zone biogeography and habitat specificity of the mulga ants make them potentially useful indicator species. The identification of two species each with distinctive nests will facilitate mapping and monitoring at different spatial scales.

STABLE ISOTOPIC COMPOSITION OF ANTS (INDICATOR 2C)

The stable isotopes of carbon and nitrogen are now being used extensively to explore the structure of food webs and ecosystems. Producers vary in the bio-chemical pathways these use in photosynthesis and these differences change the ratio (referred to as delta C) of the carbon stable isotope ^{13}C to the normal atom ^{12}C in the plant tissues. Terrestrial vegetation includes plants with C3 photosynthesis (the majority of woody plants) and C4 (and CAM) photosynthesis (a proportion of grasses and halophytes). C3 plants from the arid Lake Eyre region had delta C values of between -32 and -23 ‰ whilst the values for C4 plants were between -15.5 and -12.8 ‰ (Johnson *et al.* 2005).

Other producers including cyanobacteria, micro-algae and macro-algae also have distinctive photosynthetic pathways and stable isotope ratios. Herbivores incorporate the carbon stable isotope signature of their diet into their own tissue more or less unaltered, as do the predators which feed on

them. Consumers generally consume the carbon assimilated from the variety of plants in their habitats such that delta C is an indicator of the foraging habitat.

Plants absorb nitrogen from the soil or, in the case of legumes, from symbiotic nitrogen-fixing bacteria in their roots. Processes in nitrifying and de-nitrifying bacteria alter the form of nitrogen available and the ratio of the nitrogen stable isotope ^{15}N to the normal ^{14}N atom in the soil. Inorganic nitrogen (nitrate) has a higher delta N than organic nitrogen (ammonium). Particularly low delta N values occur when the source is gaseous nitrogen fixed by bacteria. Nitrogen-fixing bacteria may be found in the root nodules of legumes, on the soil surface or aquatic environments (cyanobacteria), in lichens or in the guts of termites. The N stable isotope ratios in plant tissues reflect the sources of nitrogen available. Some habitats have characteristic sources of nitrogen so the delta N signature can also be an indicator of the foraging areas used by animals.

During digestion animals differently excrete the lighter ^{14}N atoms and incorporate the ^{15}N isotope in their tissues leading to an increase in delta N. This increase is more or less consistent at around 2.5 – 3.0 ‰ with each step in the food chain. Thus, if the base level of delta N in the producers within a habitat is known, then the value in the tissues of a resident animal will indicate its mean trophic level.

Ants are the dominant omnivorous consumers in the semi-arid habitats at CDR. Most species have diets that a combination of honeydew (nectar), seeds and animals, taken either by scavenging or predation. Termites and other ants are a significant dietary component in some species. As such the tissues of ants should reflect both the carbon and nitrogen stable isotope signature of their habitat. A change in the biomass of different producers and therefore the sources of carbon (or energy flow), should be reflected in the isotopic composition of the ants. One such shift that is postulated as a consequence of climate change is in the relative contribution of C3 and C4 plants in plant communities.

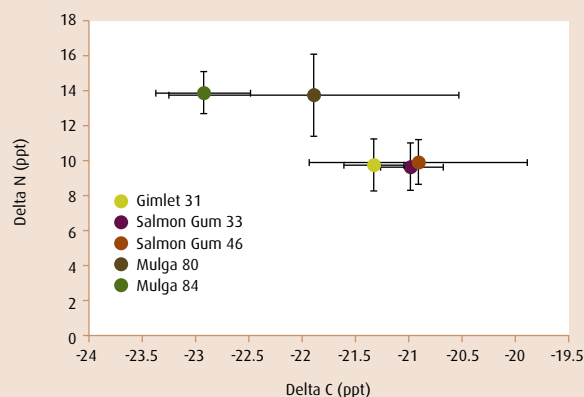
Stable isotope analysis is undertaken by commercial laboratories using an international standard methodology. The samples from the pilot projects were analysed at the Natural Isotopes laboratory at Edith Cowan University.

Protein based tissues should be selected for stable isotope analysis. Calcareous tissues, lipids and gut contents should be avoided. The ants used in this investigation were sorted into species. The 3-5 most abundant species at each of the study sites were selected for analysis. Some species (or their taxonomic equivalents) were common to all five study sites.

The ant (species by site) samples were frozen and then crushed with a mortar and pestle. The chitinous (exoskeleton) material was vibrated away from the waxy abdominal and gut contents (sticking to the surface of the mortar) and separated. The chitin fragments were then ground to the consistency of flour and labelled for the laboratory.

In Figure 2 the mean delta C values are plotted against the mean delta N values for each study site (NB. this is the mean for all species samples at each site). The error bars are standard deviations.

Figure 2: Carbon and nitrogen stable isotope signatures in ants at Observatory study sites. Error bars are standard deviation.



The Salmon Gum/Gimlet woodland sites form a distinctive cluster with no significant differences between mean delta C or delta N. Mulga site CDR 80 and CDR 84 have significantly higher delta N values than the Salmon Gum/Gimlet sites. The delta C value at Mulga site CDR 84 is significantly lower than that at the Salmon Gum/Gimlet woodland sites. The delta C at CDR 80 is intermediate and has a high variability and does not differ significantly from the other sites.

The difference in delta carbon between Salmon/Gum woodland and mulga sites is probably the result of variations in the proportion of C3 and C4 plants in the producer biomass. The Salmon/Gum woodlands have an open understorey of palatable *Atriplex* (a C4 plant) that is not present in the mulga. The dominant *Acacia* stratum in the mulga habitats is made up entirely of C3 shrubs. The presence of C4 plants would increase the delta C value of the Salmon Gum/Gimlet woodlands relative to mulga woodlands (ie. C4 plants have delta C signatures of around -14‰). The delta C at the mulga site CDR 84 is wholly within the range of values exhibited by C3 plants (Johnson *et al.* 2005).

The mulga sites (CDR 80 & 84) had significantly higher delta N values than the Salmon Gum/Gimlet woodland sites (CDR 31, 33 and 46). Mulga soils are known to have high levels of inorganic nitrogen associated with high delta N in foliage. However, the source of this nitrogen does not appear to be nodulation in the leguminous flora. The explanation may be in the nitrogen fixation by bacteria in termites and the subsequent bacterial nitrification of the biomass and wastes of these insects (Pate *et al.* 1998). Termites are extremely abundant in mulga vegetation. In any event the high delta N signature of mulga habitats appears to be diagnostic and may help discriminate the carbon (energy) flow from these habitats from other C3 dominated vegetation types.

Changes in regional climate are expected to influence the balance of C3 and C4 plants in vegetation with significant implications for habitat structure and energy flow. C3 plants evolved at a time when global atmospheric CO2 levels were relatively high and may be stimulated by the anthropogenic increases forcing global warming. C4 plants evolved later and are much more efficient in using water in photosynthesis and are better adapted to warm growing seasons. The climate change modelling suggests that the north-eastern wheatbelt should become hotter and drier. The rainfall that does occur will shift from the winter to the summer months changing the main growing season. These changes should in theory favour C4 plants but the outcome is very uncertain. Stable isotope analysis of a dominate consumer community (ants) would

appear to have considerable potential for monitoring these fundamental changes in ecosystem structure and function. It may be valuable to extend ant sampling to the other major habitats on CDR.

MICROBAT COMMUNITIES (INDICATOR 3A)

A microbat community of at least seven species has been identified at CDR. The overall relative abundance of these species based on the bat-detector survey is presented in the table below.

Microbat Species	Overall % frequency of CDR bat-detector contacts
Gould's Wattled-bat – <i>Chalinolobus gouldi</i>	65.9
Western Broad-nosed Bat – <i>Scotorepens balstoni</i>	17.6
Free-tailed Bat – <i>Mormopterus sp</i>	7.7
Chocolate Wattled-bat – <i>Chalinolobus morio</i>	4.3
White-striped Mastiff Bat – <i>Austronomus (Tadarida) australis</i>	3.2
Lesser Long-eared Bat* – <i>Nyctophilus geoffroyi</i>	0.8
Inland Little Brown Bat – <i>Vespadelus baverstocki</i>	0.5

* Long-eared Bats cannot be readily identified from ultra-sonic recordings of their calls.

Only five of the seven microbat species recorded with the bat-detector were captured in mist nets or harp traps, these being *Chalinolobus gouldi*, *Scotorepens balstoni*, *Austronomus australis*, *Nyctophilus geoffroyi* and *Vespadelus baverstocki*. It is difficult to separate the frequency-modulated signals of *Nyctophilus* species. The undescribed Inland Long-eared Bat (2008) may eventually be recorded.

Weather and seasonal factors have a marked effect on bat activity and detection. The results from the study sites were highly variable and an increased sampling intensity will be necessary to monitor changes in microbat communities.

SEASONALITY / MIGRATION OF THE WHITE-STRIPED MASTIFF BAT (INDICATOR 3B)

Bullen & McKenzie (2005) found that the White-striped Mastiff Bat (*Nyctinomus* or *Austronomus australis*) was a partial migrant. During the summer months (the reproductive period) all records were from south of 29°S latitude. During the winter months a proportion of the population moved northward into the arid zone as far north as the Great Sandy Desert. The large flight muscles in this species generate significant heat and impose a temperature limit on activity. During summer White-striped Mastiff Bats are restricted to areas where the mean monthly minimum (night) temperature does not exceed 20°C



White-striped Mastiff Bat captured over the Homestead dam.

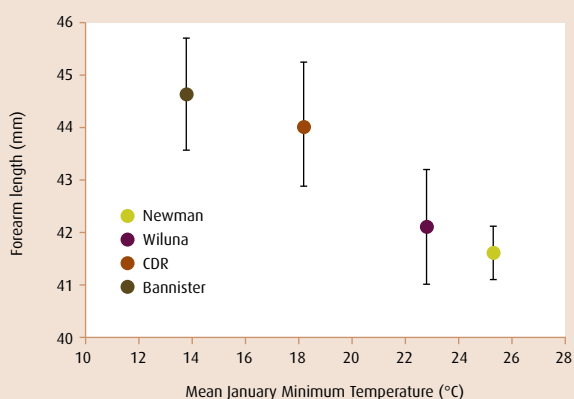
The Homestead at CDR lies at 29°S slightly north of the recorded southern limit. Monthly minimum temperatures in January and February are close to the 20°C threshold. Female White-striped Mastiff Bats captured near the Homestead in January were lactating, evidence of local reproduction during the summer months. The species was recorded on the bat-detector in November, March and April but absent in May and June samples. Currently White-striped Mastiff Bats are a summer breeding species at CDR probably migrating northwards in the cooler months. A relatively slight increase in summer night temperatures would see this species switch from a breeding species to a winter migrant at this location.

CLINAL MICROBAT SPECIES (INDICATOR 3C)

Two of the microbat species that are common at CDR, Gould's Wattled Bat and the Lesser Long-eared Bat, have wide distributions across most of Australia and are known to vary significantly in size. According to Bergmann's Rule, mean body size in widespread clinal species should increase with decreasing temperature. Clinal species may therefore be useful subjects to monitor character displacement (or micro-evolution) in a changing climate.

To confirm that these species are in fact clinal, and that the change in size is related to environmental temperature, we have compared the forearm lengths of bats from a number of Western Australian localities in the arid shrublands and south-west region. The figure below shows the mean forearm lengths for Gould's Wattled Bat plotted against mean January minimum temperatures (error bars are standard deviations).

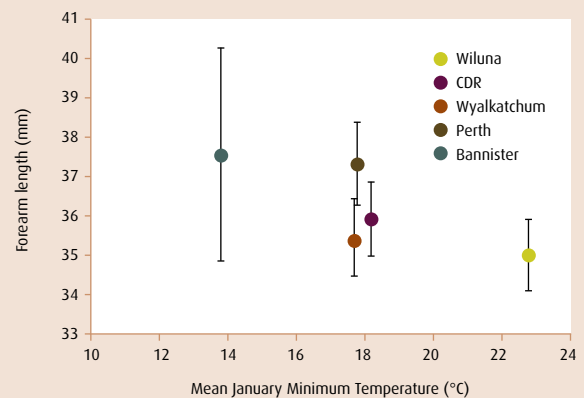
Figure 3: Forearm length (mm) in samples of female Gould's Wattled Bats from four localities.



There is strong support for the existence of a temperature controlled cline in Gould's Wattled Bat. CDR animals are currently closer to south-west forest populations than to those from the mulga zone. Increasing temperatures should see character displacement towards a shorter forearm length.

A remarkably similar pattern is evident in the Lesser Long-eared Bat (below). The forearm length of CDR Long-eared Bats is probably not significantly different from populations in the wheatbelt. However CDR forearms are smaller than observed in populations in the south-west (Perth, Bannister) and larger than those from the Murchison mulga zone at Wiluna.

Figure 4: Forearm length (mm) in samples of female Lesser Long-eared Bats from five localities.



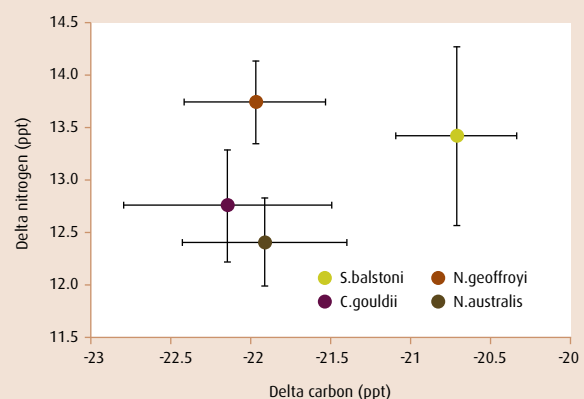
STABLE ISOTOPIC SIGNATURES IN MICROBATS (INDICATOR 3D)

Bats operate on a much larger spatial scale than ants, potentially foraging over a range of vegetation types or land systems. The stable isotope signatures in bat tissues should provide information on the responses of microbats to shifts in prey resources forced by shifts in climate. Further, the analysis of changes in stable isotope signatures might be a useful indicator of changes in ecosystem structure and function on a broader landscape scale.

Fur samples were collected from the four most frequently captured microbat species at CDR. The fur was clipped from the mid-dorsal region using fine dissecting scissors. Fur samples were examined to remove any extraneous matter and labelled for the Stable Isotope laboratory. The fine diameter hair did not require further grinding or processing.

The Figure below plots the delta C against delta N values for each microbat species. Error bars are standard deviations.

Figure 5: Mean carbon and nitrogen stable isotope values from four bat species at Charles Darwin Reserve. Error bars are standard deviations.



Chalinolobus gouldii, *Nyctophilus geoffroyi* and *Nyctinomus australis* share broadly overlapping delta carbon signatures indicating foraging over a similar range of habitats (dominated by C3 flora). *N. geoffroyi* clearly forages at a higher mean trophic level than *C. gouldii* and *N. australis* despite the much larger size of the latter species. The 'flutter-glean' and 'sit and wait' foraging methods used by Long-eared Bats may lead to a broader diet that includes more predatory insects and spiders, compared to the moth dominated diets of the other two high-flying species.

All three species occur in a wide variety of habitats over their vast ranges and their overlapping delta carbon signatures indicate that there is no habitat specialization on CDR. The arid zone species *S. balstoni* however has a significantly different mean delta carbon suggesting that its foraging may be limited to certain habitats on CDR. The delta C values indicate that the vegetation in these habitats contains a relatively high proportion of C4 plants or other producers (the salina system in the region is a possibility). Further sampling of 'within-habit' ant community stable isotope signatures may help identify these habitats.

DUNNART GUILD (INDICATOR 4)

Three species of Dunnart *Sminthopsis crassicaudata*, *S. dolichura* and *S. gilberti* were captured during the biodiversity survey of the five Observatory study sites. The Little Long-tailed Dunnart was trapped at all sites, *S. crassicaudata* was only caught at the two mulga sites CDR 80 & 84 whilst *S. gilberti* was restricted to the Salmon Gum/Gimlet woodland sites CDR 31, 33 & 46 (and only in the winter sampling). The overall capture rate was considered sufficient to use the Dunnart Guild as a ground-fauna indicator of climate induced changes in the monitored habitats. It has been observed that stress (probably from the drought) caused some Dunnarts to lose their fur.



PENGUIN WATCH MONITORING PROGRAM

BACKGROUND

Little Penguins are coastal foraging piscivores (Cullen *et al.* 1992). In south-western Australian waters they forage mainly on schooling clupeid fishes such as sardines *Sardinops vagax* and Sandy Sprat *Hyperlophus vittatus* (Connard 1995, Wienecke 1989). Successful reproduction depends on adequate aggregations of prey fishes within about 20km of Little Penguin breeding colonies. For the colony on Penguin Island the foraging areas are located immediately to the south in Warnbro Sound, and in Comet Bay north of the natural entrance to the Peel Harvey estuary (Wooller *et al.* in review, B. Cannell pers.comm). The preferred foraging areas for the penguins breeding on Woody Island are not known but are likely to be within the Esperance, Bay of Isles.

The contaminant burdens in the southern metropolitan coastal waters of Perth were investigated in some detail between 1991 and 1994 (Department of Environmental Protection 1996). Warnbro Sound and Comet Bay lie 10 – 20 km south of the main sources of metals contamination, from industrial and wastewater discharges into Cockburn Sound and the Sepia Depression wastewater outfall. The most likely sources of contamination in these areas are from urban stormwater and the Peel Harvey estuary, which is a eutrophic system.

The contaminant burden adjacent to the relatively small and unindustrialised community of Esperance is likely to be less, although the minerals exports from the Port have been responsible for localised contamination of the terrestrial and marine environment with metalliferous dust including iron oxide, nickel sulphide, lead carbonate and manganese). The Esperance coast and Port basin lie within the potential foraging range for Little Penguins from Woody Island.

This pilot project evaluates the potential to monitor two aspects of the marine environment using the collection of discarded penguin feathers, these are;

1. changes in penguin diet and the availability of prey species using stable isotope analysis, and
2. differences in heavy metal contamination at different locations using chemical analysis.

Management objectives

The Environmental Protection Authority (WA) has articulated its values and objectives for the Perth Coastal Waters (EPA 2000). Their policy document encompasses the southern metropolitan coastal waters within the foraging range of Little Penguins breeding on Penguin Island. The areas of Warnbro Sound and Comet Bay have been designated level 1 for the Environmental Quality Objective (EQO 1) for the maintenance of ecosystem integrity. This is defined below:

ECOSYSTEM HEALTH EQO 1 - MAINTENANCE OF ECOSYSTEM INTEGRITY.

Ecosystem integrity, considered in terms of structure and function, will be maintained throughout Perth's coastal waters. The level of protection of ecosystem integrity shall be high (E2) throughout Perth's coastal waters, except in areas designated E3 (moderate protection) and E4 (low protection).

Level 1 designates the objective of total protection with no detectable changes from natural variation.

Such an objective requires sufficient surveillance of ecological indicators to characterise the range of natural variation. Unfortunately such data is largely lacking.

The Management Plan for the Shoalwater Islands Marine Park (which does not fully encompass the foraging range of the Little Penguins from Penguin Island) has the following objectives (Marine Parks & Reserves Authority 2007):

Water Quality – *To ensure the water and sediment quality of the marine park is not significantly impacted by future human activities.*

Little Penguins – *To ensure the abundance of Little Penguins is not significantly impacted by a reduction in available prey species or from physical disturbance by boats or boat strikes in the marine park.*

The Water Quality objectives are broadly consistent with the EPAs environmental quality objectives. Again there is inadequate information on background levels of key contaminants particularly in the biota.

It is necessary for the Little Penguin - prey abundance objective to have a time series that relates Little Penguin abundance to prey availability. However, it has not been feasible in the past to monitor the size of the population with sufficient accuracy to be useful for monitoring incipient change. A broken time series for breeding performance does exist (B. Cannell pers.com.) and this could be linked to indicators of dietary shift (ie. from stable isotope analysis).

INDICATOR CONSTRUCTION

ECOLOGICAL MODEL	TAXA / COMMUNITY/ FUNCTIONAL GROUP	METRICS	INDICATOR
Little Penguins are top predators capable of integrating marine ecological processes occurring on a spatial scale of around 100km ² .	Little Penguin (<i>Eudyptula minor</i>) feathers at distinct two colonies.		
1. The stable isotope ratios of carbon and nitrogen in Penguin feathers should reflect the habitat and trophic level of the prey species.		1. Stable isotope ratio of carbon ¹³ C to ¹² C (delta carbon) and nitrogen ¹⁵ N to ¹⁴ N (delta nitrogen) expressed in parts per thousand ‰.	The relationship between delta C and delta N signatures and breeding performance. Changes in the frequency of 'poor' diet /foraging years.
2. Bird feathers are efficient accumulators of metal contaminants. These metals may be sequestered in the feathers and reflect the internal (eg. blood) contamination burden or bound ectopically reflecting metal levels in the external environment (eg. on soil, water or vegetation).		2. Concentrations of selected metals and selenium (mg/kg) in penguin moult or mesoptile down feathers.	2a. The differences in metal concentrations in penguin feathers from colonies in distinct marine environments. 2b. Changes in the metal concentrations of penguin feathers at sampled colonies over time.

Resources & partnerships

Penguin feathers can be easily collected by authorised citizen scientists following simple protocols to ensure sample independence and to manage contamination. Some financial resources are required to commission both stable isotope and chemical analysis. For the Penguin Watch pilot project the stable isotope analysis was undertaken by a commercial laboratory (Natural Isotopes) using an international standard methodology. The chemical analysis was conducted using NATA accredited methodology by the Chemistry Centre of Western Australia.

The Penguin Watch program would require around \$2000 pa in laboratory costs. Small grants and government agencies assisted in meeting laboratory costs for the pilot project. The use of marine bio-accumulators is a much more efficient way of monitoring diffuse marine contamination than water or sediment sampling. Long-term funding arrangements between citizen science groups and management agencies may therefore be negotiated.

Reporting & communications

All monitoring projects necessitate the periodic reporting of results to natural resource managers and the community. The frequency of reporting will depend on the rate at which interpretable results accrue and the magnitude of the environmental risk being monitored.

Penguin Watch will report on the results of the baseline / bench-marking /pilot project and then on a five year cycle. This will include publication in the scientific literature. Reporting will be directed at the natural resource management agencies (Marine Parks & Reserves Authority,

Department of Environment & Conservation, Department of Fisheries, EPA and Cockburn Sound Council) and the public via the media.

Pilot projects

PROJECT 1: USING PENGUIN FEATHERS TO MONITOR METALS AND SELENIUM IN THE MARINE ENVIRONMENT

INTRODUCTION

Bird feathers are potential storehouses of information, including data on nutritional state, diet and metal contaminants (see What's in a feather?, p. 9). The collection of moulted or moulting feathers is non-invasive and as such an ideal method for community-based marine monitoring programs. This pilot project used the analysis of penguin feathers to bench-mark marine metal contamination in the marine environments in two contrasting regions.

METHODS

Recently shed adult feathers were collected from breeding burrows during the moulting period. Samples were collected on Penguin Island (N=9) in early January and from Woody Island (N=10) in early February 2009. Shedding mesoptile (secondary) down was collected from well grown penguin chicks between October and December 2008 on Penguin Island (N=10) and in October 2008 from Woody Island (N=4).

Sample weights for Penguin down ranged from 0.03 – 0.25g and adult feathers from 0.12 – 0.52g. The samples were washed first in acetone and then in de-ionized water, labelled

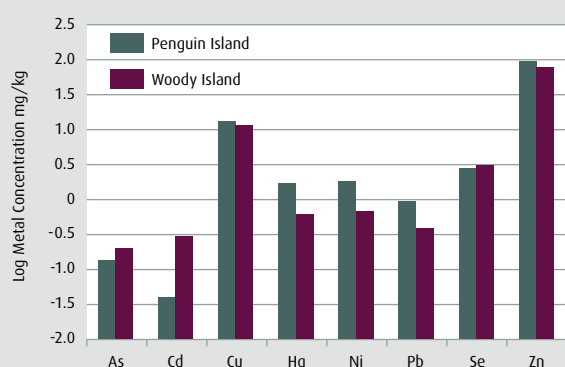
ready for digestion and sent to the Chemistry Centre of WA (a NATA accredited laboratory) for analysis.

The adult moult feathers were analysed for Arsenic (As), Cadmium (Cd), Copper (Cu), Mercury (Hg), Nickel (Ni), Lead (Pb), Selenium (Se) and Zinc (Zn). Chick down was only analysed for Pb and Ni as these were contaminants of particular interest in Esperance waters given the Port's recent contamination history.

RESULTS

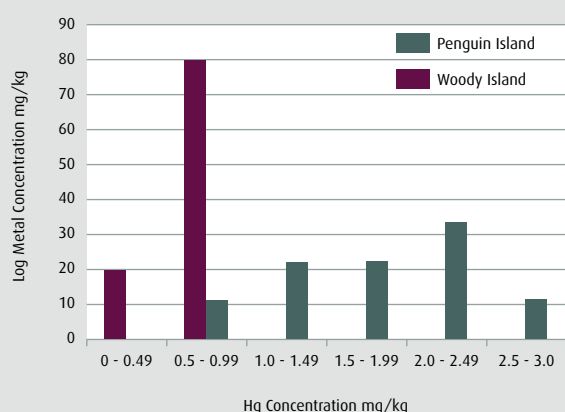
Figure 1 indicates a consistent pattern in the relative concentration of the various elements in the adult feathers of Little Penguins. Within that pattern however there were differences in concentration for some elements between the Penguin Island and Woody Island penguin colonies.

Figure 1: The concentrations of various metals in adult penguin feathers.



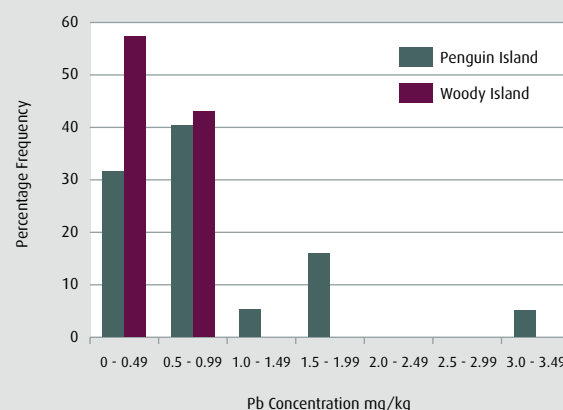
The levels of Hg, Ni and Pb were higher in Penguin Island birds, these differences were significant for Hg (Mann-Whitney $U=5$, $p<0.002$) and for Ni ($U=17$, $p<0.05$). Although Pb concentrations in Penguin Island birds were nearly 3 times higher than those on Woody Island the difference was not significant. The reason for this can be seen by comparing the distributions of Hg and Pb concentrations across the two colonies in Figure 2a.

Figure 2a: The distribution of Hg concentrations in the Penguin and Woody Island sample populations.



There is little overlap between the relatively high concentrations in the Penguin Island sample population and the lower values in the Woody Island sample population. By contrast, there is significant overlap at the low end between the Pb concentrations on Penguin and Woody Island (Figure 2b). Penguin Island however has a number of individuals showing elevated Pb levels in their moulted feathers.

Figure 2b: The distribution of Pb concentrations in the Penguin and Woody Island sample populations (includes adult feather and chick down samples).

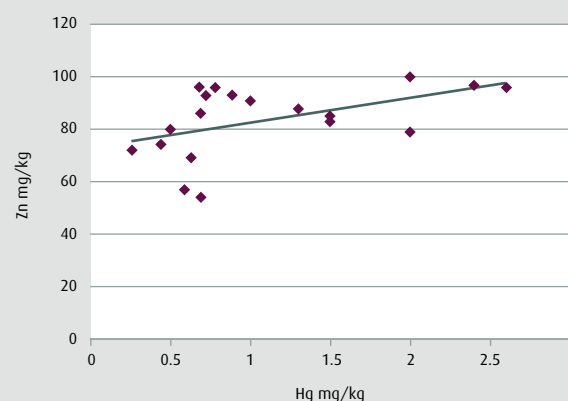


Mean Pb concentrations in chick down on Penguin Island (0.84 mg/kg) were lower but did not differ significantly from those of adult moult feathers (0.98 mg/kg). Similarly mean Ni concentrations in chick down samples (0.90mg/kg) were lower than in adults (1.78mg/kg) from the same colony, but again this was not significant.

As, Cu, Se and Zn concentrations in adult penguin moult feathers did not differ significantly between the Penguin and Woody I colonies. However Cd levels in the Esperance birds were significantly higher than the birds from the southern coastal waters of Perth ($U=7$, $p<0.002$).

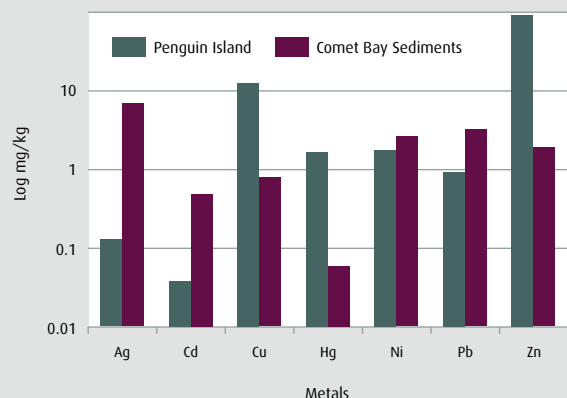
Interestingly Hg and Zn concentrations in adult moult feathers showed a positive linear correlation (Figure 3, $r=0.4906$, $p<0.05$). There was also a suggestion of a negative linear relationship between Hg and Se although this did not reach significance ($r=0.4209$, $p<0.1$). Both Zn and Se are thought to have a role in the chemistry of sequestering methyl mercury in feathers (Eisler 2000).

Figure 3: Correlation between concentrations of mercury and zinc in Little Penguin adult moult feathers.



The Southern Metropolitan Coastal Waters Study (Department of Environment WA) measured sediment concentrations of metals within the main foraging area of the penguins from Penguin Island in Comet Bay. Figure 4 compares the sediment concentrations (measured in the 1990s) and the levels in adult moult feathers.

Figure 4: Comparison of metal concentrations in penguin feathers and Comet Bay sediments (plotted on a logarithmic scale).



A clear distinction can be made between elements that have higher concentrations in the sediments (ie. As, Cd, Ni and Pb), that Little Penguins bio-accumulate in their feathers, verses those that are much more concentrated in the feathers and are bio-magnified (Cu, Hg, Zn). Cu, Zn and to a lesser extent Ni are essential trace elements and the assimilation of Zn may also be important for the sequestration of Hg. Hg is bio-magnified in marine food chains and feather sequestration is the only way that toxic methyl-mercury can be eliminated from the avian body (Burger & Gochfeld 2002). Methyl-mercury is generally produced by microbial activity in low oxygen environments and is generally high in pelagic seabirds that feed on deep water meso-pelagic fish (eg. Thompson *et al.* 1998). Elevated Hg levels in coastal foraging seabird species, such as the Little Penguin, are unusual.

DISCUSSION

Little Penguins foraging in the southern metropolitan coastal waters of Perth had elevated levels of Hg, Ni and Pb in their feathers compared to birds feeding in the waters off the small coastal town of Esperance, despite fugitive Ni and Pb dust emissions from the Esperance Port. The sources for the elevated Hg and Ni levels are likely to be in the marine food chain as the trend was uniform across the sample population. The significantly elevated levels of mercury (which will be methyl-mercury in feathers – Burger 1993, Burger & Gochfeld 2002 & Eisler 2000) may arise from microbial mercury methylation in the anaerobic sediments of the eutrophic Peel Harvey estuary. (N.B. the birds from Penguin Island feed largely on Whitebait aggregations in the estuarine chlorophyll plume in Comet Bay. Their feather ¹⁵N stable isotope signatures indicate that their prey feed on producers (phytoplankton) that are significantly enriched with inorganic nitrate (ie. from a more eutrophic environment than the background coastal waters).

The highest Hg levels recorded (2.6 mg/kg) were below the threshold of 5mg/kg (in feathers) thought to potentially have clinical effects on seabirds (Burger & Gochfeld 2002). However these levels are sufficiently high to warrant further investigation and continued monitoring.

The distribution of Pb concentrations in the Penguin Island birds (both adults and chicks) indicates only a proportion of individuals with relatively high Pb levels. This suggests that the origin of the contamination may not be via the marine food-chain. Historically Penguin Island had up to

28 fibro buildings most painted with Pb based paints from the 1960s and 1970s. There was probably also Pb plumbing, roof flashings and other sources in the holiday settlement. It is more likely that the patchy contamination of Penguin Island birds is the result of Pb soil contamination in and around some of the nesting burrows. The highest levels recorded (3.1mg/kg) are below the likely threshold for toxic effects (20mg/kg – Burger & Gochfeld 2002) and it is also probable that much of the plumage contamination is external and therefore relatively benign.

The mean Ni concentrations in the Penguin Island birds (1.78mg/kg) were just below those associated with Ni contaminated sites in North America (Eisler 1998) but high enough to require some further investigation as to possible sources.

The adult moult and mesoptile-down feathers of Little Penguins provide a reliable, non-invasive resource to monitor the background levels of metals contamination in our near coastal waters. Little Penguins are avian top-predators in our near coastal marine ecosystems, bio-accumulating or bio-magnifying a range of metallic elements in their plumage in a predictable manner. It would appear from this study that penguin feathers would provide a particularly cost-effective way of monitoring changes in the most toxic organic forms of Hg in our marine environment.

PROJECT 2: USING PENGUIN FEATHERS TO MONITOR CHANGES IN PREY AVAILABILITY

INTRODUCTION

The breeding success of Little Penguins breeding on Penguin Island has been monitored using marked nest boxes in since 1986 (with the exception of 2004 and 2005). A stream of research students and citizen scientists contributed to maintaining this important time series.

Over the period annual reproductive performance ranged from 0.3 to 1.3 fledged chicks per breeding pair (mean 0.8).

There are three penguin colonies in the Perth metropolitan coastal waters. These are on Carnac Island off Fremantle, HMAS Stirling in Cockburn Sound and on Penguin Island off Rockingham.

A radio-tracking project in the 1990s (Wooller *et al.* in press) and more recent satellite-tracking (Cannell pers.com) have shown that penguins from the Penguin Island colony forage to the south, primarily in Comet Bay. Longer foraging trips south of the Peel Harvey estuary are typically associated with breeding failure.

The dominant prey species during chick provisioning in successful pairs / seasons in this colony is the whitebait *Hyperlophus vittatus* (Connard 1995, Klomp & Wooller 1998, Lenanton *et al.* 2003). A number of factors contribute to whitebait abundance within penguin foraging range. The strength of the Leeuwin Current effects recruitment to the main nursery area on the northern aspect of Becher Point (separating Warnbro Sound from Comet Bay). There is generally more recruitment in strong Leeuwin Current seasons (Gaughan *et al.* 1996). The penguins take mostly adult (2+) fish so the recruitment impact on breeding performance lags by one year (Wienecke *et al.* 1995).

Another factor influencing whitebait abundance is winter rainfall suggesting the plankton transport / production from the estuarine nutrient plumes may be important for whitebait



growth and survival. The nitrogen stable isotope signatures in the feathers of penguins from the Cockburn Sound and Penguin Island colonies are very high compared to our south coast colony near Esperance. This probably reflects the supply of inorganic (nitrate) nitrogen from the eutrophic estuaries and contaminated ground-waters discharging into the Perth coastal waters (J.N. Dunlop, unpublished, Stechis *et al.* 1995).

Habitat changes from the proposed construction of a boat ramp immediately adjacent to the Becher Point could potentially alter the function of the whitebait nursery. The result could be a decline in local whitebait stocks and in the prey biomass available within foraging range of the Penguin Island colony.

This pilot project investigates the use of the carbon stable isotope ($^{13}\text{C}/^{12}\text{C}$ – delta carbon) and nitrogen ($^{15}\text{N}/^{14}\text{N}$ – delta nitrogen) ratios in penguin chick feathers to monitor inter-annual changes in diet and prey availability for Little Penguins. It is important for managers to discriminate between marine (ie. food-controlled) effects on reproductive success and other factors (eg. land – based human disturbance).



METHODS

Delta Carbon Values

Stable isotope ratios of carbon usually show a slight ($<1\text{‰}$) enrichment in ^{13}C with trophic level. As carbon ratios undergo little alteration in consumer organisms they are broadly indicators of the carbon source at the base of the food chain. Phytoplankton blooms in offshore or oceanic marine environments are generally more depleted in ^{13}C than inshore ones. Estuarine phytoplankton may also have a distinctive delta carbon. Higher plants such as mangroves (with C3 photosynthesis), seagrasses (with C4 photosynthesis), red and brown macro-algae and cyanobacteria all have distinctive delta carbon ranges.

Delta Nitrogen Values

When animals digest plants or other animals they differentially excrete the lighter ^{14}N atoms and concentrate the heavier ^{15}N ones in their proteins. The result is the stable isotope ratios of nitrogen show stepwise enrichment with trophic level of 3-7 ‰. The delta N values in animal tissues are therefore indicative of mean trophic level (position in the food chain).

Delta N is also influenced by the sources of nitrogen to the producers at the base of the food chain.

Nitrogen from “fresh” inorganic (nitrate) sources such as from marine upwellings, sewage or artificially enriched groundwater or the mineralisation of guano tends to produce relatively high ^{15}N values in the producers (plants) of between 4 and 7 ‰. Plants taking up organic ammonia nitrogen tend to have ^{15}N signatures around 2 ‰. Cyanobacteria including the species in algal mats, or forming marine slicks (eg. *Trichodesmium*), have very low ^{15}N signatures. This presumably reflects the gaseous isotope ratios. Thus the first step on the foodchain may be higher or lower depending on the source(s) of nitrogen being used by the producers.

Sampling

Sampling took place in the Penguin Island breeding colony between September and December in each year from 2004 to 2008.

The citizen scientists involved in this pilot project were also engaged in nest-box monitoring and the capture / mark / release of penguins using implantable transponders. During these operations the moulting mesoptile (middle down) feathers were collected from the nape or throat area of large penguin chicks. A minimum of 10 individuals were sampled each season.

The down was placed in dry sterile plastic vials or ring-lock plastic envelopes and labelled with location and date. The identity of tagged animals was also recorded.

Laboratory Analysis

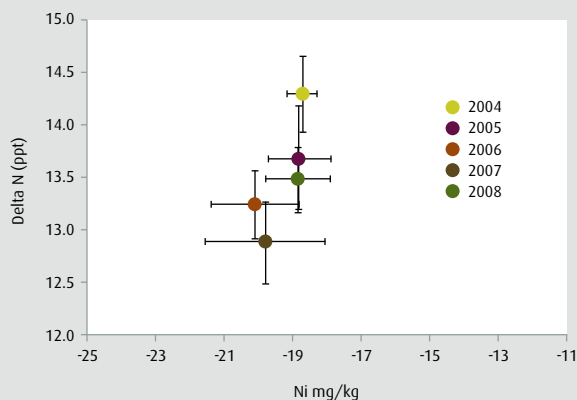
Stable isotope analysis is undertaken by commercial laboratories using an international standard methodology. The samples from the pilot projects were analysed at the Natural Isotopes laboratory at Edith Cowan University.

Prior to laboratory analysis a citizen science volunteer examined the feathers to remove any extraneous matter. The feathers were then ground to a flour-like consistency using stainless steel ball bearings in a centrifuge.

RESULTS & DISCUSSION

There were significant differences in the delta C and delta N values in penguin chick feathers between the 2004, 2005 & 2008 seasons and 2006 & 2007. Unfortunately there is no 2004 or 2005 data on breeding performance although the informal observations suggest they were late-starting and produced few chicks. The 2008 season was well below average producing 0.5 chicks per pair.

Figure 5: Stable isotopes in penguin down 2004-2008



By contrast 2006 and 2007 were among the most productive seasons recorded producing 1.2 and 1.0 chicks per pair respectively. The stable isotope signatures indicate that the differences observed in breeding performance were consistent with a major change in diet (or possibly prey location). The N signatures seem to indicate that in good years the fish-prey are more depleted in ^{15}N than in poor years. This may suggest that in poor years the penguins forage on different prey, or more probably, are restricted to foraging near shore, where there is more inorganic nitrogen in the food chain (ie. adjacent to eutrophic estuary mouths).

The pilot project indicates that the use of feather stable isotopes would be an effective and efficient way to monitor inter-annual variations in diet or prey availability. Such changes could be driven by local coastal development (ie. the proposed boat - ramp at the whitebait nursery) or local fishing pressures or large-scale impacts such as climate change induced shifts in the behaviour of the Leeuwin Current.



LANCELIN ISLAND MARINE CLIMATE CHANGE OBSERVATORY MONITORING PLAN

BACKGROUND

THE PROBLEM

A scientific review and workshop facilitated by the Conservation Council of WA (CCWA) in June 2008 confirmed that structured, long term observations on biological responses to climate change in Western Australian marine ecosystems were very limited. Such observations were however essential in underpinning any climate change adaptation strategy for biodiversity conservation and for the validation of model-based approaches.

THE OBSERVATORY CONCEPT

One approach to dealing with this deficiency is to adopt the 'observatory concept', ie. to concentrate research / monitoring effort into strategically significant locations for long periods of time.



Lancelin Island Nature Reserve (looking west).

Lancelin Island Nature Reserve (off the coastal settlement of Lancelin) has been a focal point for seabird research in south-western Australia. Significant changes have been observed in the distribution and abundance of at least eight tropical seabird species populations off south-western Australia since 1900, south of the Houtman Abrolhos Islands. The observed changes have involved a southward shift in breeding distribution or the rapid growth of colonies located on or beyond their previous limits. The rate of change appears to have accelerated over the last three decades of the 20th century.

Lancelin Island has been colonised by four species of tropical terns since 1900. The Bridled Tern (*Onychoprion anaethetus*) established sometime prior to the 1950s, the Roseate Tern (*Sterna dougallii*) in the 1970s and the Common Noddy (*Anous stolidus*) and Sooty Tern (*Onychoprion fuscatus*) in the 1990s. A study of a 'frontier colony' of Common Noddies that encompassed its entire establishment period was used as a framework for a 'demographic transition model' extrapolated to other frontier colonies (Dunlop 2005, Dunlop *in press*).

The establishment of frontier colonies of tropical seabirds south of their original distributional limits is an indicator of changes in ocean climate in offshore pelagic ecosystems. A wide range of historical observations together with more detailed recent studies have been brought together to propose a general hypothesis to explain the observed changes in tropical seabird population dynamics in the region. The increased frequency of the *El Nino* and its negative impact on food availability appears to have been a major driver of the population dynamics in tropical pelagic species in the region.

Since 2000 however the relationship between the El Nino Southern Oscillation (ENSO), the Leeuwin Current and breeding success in the tropical pelagic seabird species has broken down. Increasing years of poor breeding performance (particularly at the Abrolhos) are being recorded outside *El Nino* periods. This has been accompanied by significant seasonal delays in the onset of breeding in the four tropical pelagic tern species. It is now postulated that a regime shift has occurred in offshore and oceanic plankton food-chains off central WA in recent years.

The seabird colonies on Lancelin Island have been, and will continue to be, indicators of marine climate change. The seabird research history on the Island makes it an ideal candidate for a marine climate change observatory.

In 2001 a Fish Habitat Protection Area (FHPA) was declared over the small lagoon area on the western side of Lancelin Island. The management plan for the area excludes fishing and anchoring providing some protection for its benthic habitats from localised impacts (Department of Fisheries *et al.* 2001). A citizen science survey conducted by the Australian Marine Conservation Society (AMCS) and Friends of Lancelin Island (FLI) was conducted to support the community driven proposal to establish the FHPA. This survey documented the limestone reef and sandy floor habitats of the lagoon. Although dominated by macroalgae the limestone reef structure was found to support at least eleven species of hard (scleractinian) corals.

The recruitment, establishment and survival of hard corals, which are near the limit of their distribution at this latitude (31°S), are potential indicators of climate change (particularly of rising sea-temperature). Changes in the balance between the macroalgae and coral are a predicted consequence of shifts in ocean climate resulting from global warming.

The hard coral community (and associated biota) of the Lancelin Island FHPA provides another set of potential indicators for a marine climate change observatory.

Management objectives

The management plan for the Turquoise Coast Island Nature Reserves (which includes Lancelin Island) has no specific objectives for seabird populations other than for general protected species conservation (Department of Environment & Conservation 2004). There are also no objectives that specifically relate to the adaptive management of pressures introduced by climate change.

The Lancelin Island FHPA was established to conserve and protect its fish and aquatic ecosystem for conservation and nature appreciation purposes. No particular resource condition or state was articulated in the form of an objective (Department of Fisheries *et al.* 2001).

Current official management plans or strategies provide little context for marine climate change monitoring either at Lancelin Island or more broadly. The following unofficial objective is proposed.

The objective of the Observatory project is to ‘**detect incipient biological responses to changes in marine climate variables to inform adaptation strategies for biodiversity conservation for the islands and waters of the lower central west coast region (ie. Turquoise Coast)**’.



Indicator construction

The more detailed aspects of the objective are encapsulated in the construction of the individual indicators set out in the table below. The table also summarises the description of ecological models, indicators, sampling design and metrics.

INDICATOR CONSTRUCTION TABLE

Ecological model	Taxa / Community/ Functional Group	Metrics	Indicator
Most of the ‘frontier’ seabird colonies studied are still increasing in size. One is known to have declined towards extinction in recent years (Red-tailed Tropicbird on Sugarloaf Rock). Trends in the number of pairs indicate the availability of local marine prey resources. Ultimate colony size may indicate the ‘carrying capacity’ of ‘frontier’ breeding areas that have resulted from shifts in marine climate.	Common Noddy, Sooty Tern, Bridled Tern and Roseate Tern	Number of breeding pairs based on counts of nests with eggs.	Changes in the number of breeding pairs in ‘frontier’ tropical tern colonies.
The mean age of breeding seabirds tends to be relatively young in new rapidly growing colonies and older in established, stable ones. Low adult survivorship, or low reproductive output caused by climate driven prey-resource pressures would see a decline in the age of first breeding.	Common Noddy	Proportion of marked known-age Noddies in each age class.	Changes in the age structure of ‘frontier’ tropical tern colonies.
Changes in marine climate may affect the timing of breeding by altering the seasonality of prey resources. Later breeding is generally associated with a decline in reproductive performance.	Common Noddy, Sooty Tern, Bridled Tern and Roseate Tern	Date on which the first eggs were recorded each season.	Changes in the timing of egg-laying in ‘frontier’ tropical tern colonies.
Lancelin Island lies to the south of the region where hard corals are reef-building at present. However changes in sea-temperature could see the settlement and establishment of more species at this latitude. Increased growth rates could see a shift from substrate dependent to reef-building corals.	Selected hard coral species.	a. Number of new settled polyps in sample plots each year. b. Number of colonies surviving in sample plots each year. c. Change in dimensions of monitored coral colonies.	Changes in recruitment, survival and growth of selected hard corals in relation to sea-temperature.
At the boundaries of tropical and temperate waters corals compete with macro-algae for space on reefs. Increasing sea temperatures may favour corals in habitats currently dominated by macroalgae.	Macroalgae and hard coral species / cover.	Percentage substrate-cover by macro-algae and hard corals in sample plots.	Changes in relative abundance (percentage cover) of hard corals and macroalgae in relation to sea-temperature.

Resources & partnerships

Seabird research on Lancelin Island has been conducted by Dr J.N. Dunlop, the Friends of Lancelin Island and numerous visiting citizen-scientists (including trainee bird-banders) since 1994. Banding materials and administration were provided by the Australian Bird & Bat Banding Scheme (ABBBS). It is anticipated that a similar mix of participants will continue the long-term monitoring of the Island's seabird colonies for the Observatory project.

Data has been collected from an automatic sea-temperature (Tidbit) logger over a number of years. This has been done in collaboration with retired oceanographer Alan Pearce. This partnership is proposed to continue indefinitely.

A pilot Masters project is being developed that will establish a rigorous methodology and benchmark for the ongoing monitoring of the population dynamics of the hard corals within the Lancelin Island Lagoon.

Current arrangements for the monitoring program for the Lancelin Island Marine Climate Change Observatory are informal. Ultimately the necessary longevity for the project will depend on it having a structure to manage resources and provide for a succession of participants. The current partners will need to develop an appropriate entity and structure.

Reporting & communications

The seabird research has been reported periodically through publication in the scientific literature. However monitoring data from the Marine Climate Change Observatory will need to engage a wider audience including natural resource managers, decision-makers and the public. Ultimately a web-based reporting and communications facility will need to be developed and managed by the Observatory. In the shorter term this may have to be hosted by a partner organisation such as the Conservation Council of WA.

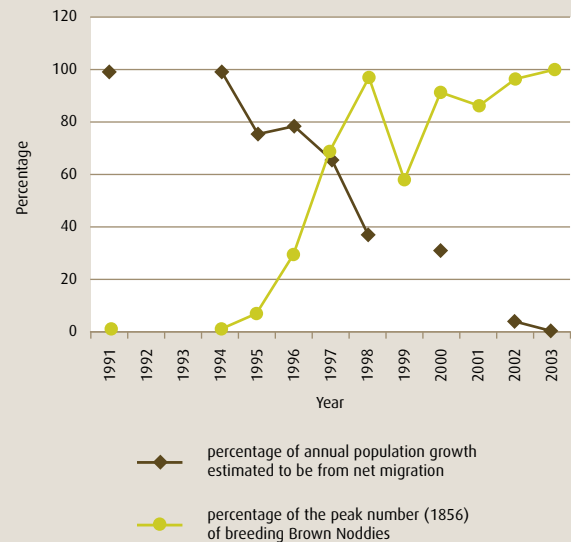
Pilot projects

SEABIRD RESEARCH

Various observers have systematically documented the seabirds of Lancelin Island dating back to the 1950s (Dunlop *in press*) and their records detail the arrival and establishment of the Roseate Tern, Common Noddy and Sooty Tern and the growth in the number of breeding Bridled Terns.

The demography of the Island's Common Noddy population has been studied through its establishment period using mark-release-recapture methods (Dunlop 2005). A high proportion of the breeding Noddies (around 1200 pairs in 2008) have been banded with ABBBS numbered alloy rings. Cohorts of chicks banded mostly at the nestling stage provide a significant known-age component in the marked population. *Figure one* shows the growth curve for the Common Noddy 'frontier' colony up to 2002, and the proportion of the colony size attributable to immigration from elsewhere.

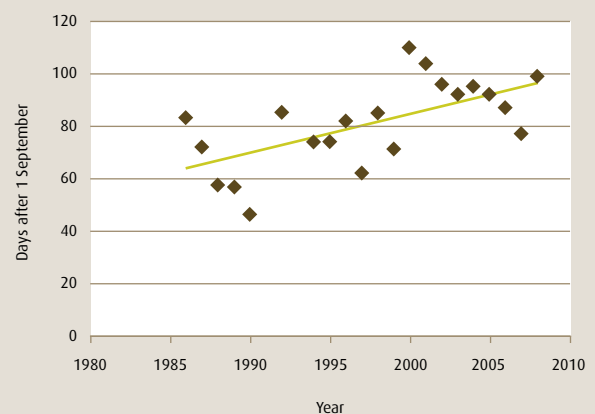
Figure 1: The establishment of the Brown Noddy (*Anous stolidus*) colony on Lancelin Island



The marked Common Noddy population and colony growth time-series provide a solid basis for ongoing monitoring. An equivalent data set is available for the much smaller Sooty Tern colony (around 30 pairs in 2008).

Bridled Terns have not been studied in detail on Lancelin Island but the colony on Penguin Island, near Rockingham, has been studied continuously using mark-recapture and other methods since 1986. This colony and the one on Lancelin Island are part of the same meta-population and seem show parallel inter-annual variations in breeding performance. On Penguin Island first laying dates were determined for 20 of the last 22 years and show that the start of the breeding season has become increasingly delayed, with probable consequences for reproductive output. *Figure two* shows the significant linear relationship between the breeding season (year) and laying date for the first egg.

Figure 2: Date of first laying in Bridled Terns between 1986 and 2008

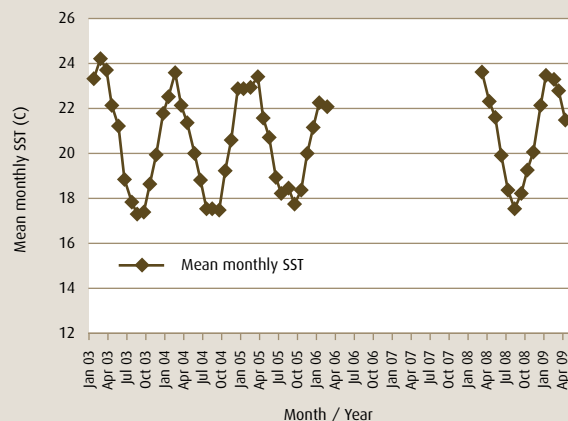


A similar pattern appears to be developing in the other tropical tern species at Lancelin Island and on the Houtman Abrolhos Islands (C. Surman pers.com.). Given the number of species and spatial scale involved it is highly probable that this change in the phenology of breeding is an indicator of a major regional shift in ocean climate. The detection of such shifts is not only important for biodiversity conservation but also as an independent indicator of large-scale shifts in the productivity of the marine environment that are impacting on the State's fisheries.

SEA TEMPERATURE MONITORING

In December 2002 a Tidbit temperature logger was installed on a permanent mooring in the Lancelin Island Lagoon FHPA. The purpose was to collect long-term sea-temperature data to investigate potential relationships with changes in the abundance of marine life.

Figure 3: Mean monthly sea surface temperature in Lancelin Island Lagoon



Two loggers were alternated on a 4-6 months cycle through their operational (battery) life. This provided temperature measurements every 10 minutes for 39 months, from December 2002 to February 2006. Due to a lack of resources the loggers could not be replaced until February 2008. Sea temperature data continues to be accumulated using these loggers. The Tidbit loggers currently in use have been superseded and the new model and software will have to be purchased within the next two years if this monitoring is to continue.

BIOLOGICAL MONITORING

The Australian Marine Conservation Society and Friends of Lancelin Island groups conducted a baseline survey in 1999 in developing the proposal for the Lancelin Island Lagoon FHPA. This survey mapped the reef seagrass and sandy-bottom areas and inventoried hard corals and fish. Eleven species of hard corals were recorded during this period. Some surveillance monitoring was undertaken in 2002.



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GLOSSARY

<i>Analogous</i>	corresponding in function but not derived from a common source or origin
<i>Asymptote</i>	point at which the rate of change in a growth curve slows and flattens
<i>Benthic</i>	living on the seabed or bottom of an aquatic environment
<i>Calcareous</i>	composed wholly or partly by calcium carbonate
<i>Chenopods</i>	Halophytic (salt adapted) plants from the family Chenopodiaceae
<i>Cryptogams</i>	Simple plants (mosses, lichens and algae) growing on the soil surface forming a crust.
<i>Clinal</i>	With a biological character (eg. size, colouration) changing consistently along a physical gradient
<i>Ectopic</i>	attached or in contact with the outside of an organ or structure
<i>Endogenous</i>	growing, proceeding or controlled from within
<i>Epiphytic</i>	plant which grows upon another, but does not get food, water or minerals from it
<i>Eutrophication</i>	aquatic environment overfed with nutrients
<i>Eutrophic system</i>	an ecosystem with excessive nitrogen or phosphorus inputs
<i>Exogenous</i>	originating or impinging for outside, from the external environment
<i>Lateritic sand</i>	Sand derived from the weathering of granite incorporating rounded pebbles
<i>Lipid</i>	any of a group of organic compounds which make up fats – they have a greasy feel and are insoluble in water
<i>Mesoptile</i>	the middle down of a developing bird chick
<i>Terrete phyllodes</i>	Narrow phyllodes with a circular cross-section and ending in a point
<i>Pelagic</i>	living at or near the surface of the ocean, associated with mobile food chains of the water column
<i>Phenology</i>	a science dealing with the influence of climate on the timing of biological events, such as flowering, fruiting, emergence, egg-laying and migration
<i>Phyllodes</i>	Reduced leaves of Australian Acacia species derived from flattened leaf- bases. An adaptation for water conservation
<i>Philopatric</i>	Returning to breed at the place of its birth or origin
<i>Salina system</i>	Saline sediment lakes and pans often remnants of major ancient but now inactive river systems
<i>Sessile</i>	attached to the seabed or to some other underwater substrate
<i>Stable isotopes</i>	Naturally occurring variations in the normal number of neutrons in atoms producing minor differences in molecular weight. Unlike radio-isotopes these do not decay and produce radiation
<i>Stochastic</i>	ongoing or continuous chance events
<i>Stressor</i>	Environmental pressure with the potential to force ecological change
<i>Trophic</i>	Pertaining to an organism's diet or energy level in the food chain.
<i>Trophic level</i>	Average energy transfer or feeding position in the food chain (eg. herbivore, planktivore / omnivore, meso-predator or top predator)

ABOUT THE CONSERVATION COUNCIL OF WA

The Conservation Council of WA (CCWA) is the State's foremost non-profit, non-government conservation organisation. We are an umbrella group for over 90 affiliate conservation groups and have been an outspoken advocate for environmental protection and a sustainable WA for over 40 years.

With your support, we can be a powerful catalyst for transforming Western Australia's economy and protecting our natural environment.

Individuals - support us

If you would like to contribute to building a sustainable WA, you can:

- Become a voice for the Environment by making a regular donation
- Make a single donation
- Become a volunteer
- Leave us a gift in your will

Groups - join us

CCWA works in partnership with other conservation groups, large and small. Become a CCWA member group and:

- Increase your group's impact
- Improve your networks and contact base
- Gain access to support, expertise and representation

For more information on how to support CCWA see our website

www.conservationwa.asn.au



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