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New Organism Introductions : a risk analysis approach used in the assessment of whether a proposed importation, development and/or release is in the interests of conservation

Michael Cameron

Biodiversity Recovery Unit, Department of Conservation, PO Box 10-420, Wellington.

ABSTRACT

Every year, organisations and individuals seek approval to introduce new species of plants, animals and other organisms to New Zealand. They must make their applications to the New Zealand Environmental Risk Management Authority (ERMA) which will decide whether the introduction is in New Zealand's best interests. The Department of Conservation (DOC) is responsible for ensuring decisions take the interests of conservation into account and do not lead to the introduction of new environmental pests, weeds or pathogens. The following paper describes the principles used by DOC in advising ERMA. ERMA is required to take this advice into account. This paper draws on experience and theory, within and outside DOC.

INTRODUCTION

Conservation managers in New Zealand know only too well the damage wrought by the ill-advised species introductions of the past. A large percentage of DOC's budget today is devoted to dealing with the consequences of introductions such as rats, possums, mustelids, broom and wasps. Despite this, deliberate introduction of new organisms into New Zealand continues and is diversifying with the advance of genetic engineering technology and the increased production of new genetically modified organisms.

One of the important things DOC can do in fulfilling its responsibilities in maintaining the public conservation estate and advocating conservation generally is to stop the further deliberate introduction of new organisms that may be environmentally damaging. DOC has no direct statutory power to achieve this. Under the Hazardous Substances and New Organisms Act 1996 (HSNO Act) it is ERMA that is empowered to receive applications and decide whether or not to approve them. When deciding, however, ERMA is required to have particular regard to DOC's submissions (s. 58).

This paper explains the risk analysis approach used by DOC when formulating its submissions and deciding whether or not to support a particular application. It draws on ideas expressed in formative discussion documents (e.g. Ministry for the Environment, 1988) and especially from the work carried out by bio-control practitioners in New Zealand and overseas. The paper is far from definitive, and hopefully one benefit of its publication will be feedback from conservation managers and scientists on their own area of expertise. Emphasis is heavily weighted toward the introduction of invertebrates because that has been the subject of most recent applications and hence the area where the most has been learned. Before moving on to give a summary of the risk analysis approach it should be noted that DOC provides its advice purely from a conservation standpoint. It does not attempt to decide whether it is in the overall interest of New Zealand for an application to be approved or declined. Departmental advice states whether a proposal is in the interests of conservation leaving the final decision as to whether the overall public interest is being served to ERMA, with advice from the other affected parties. While in most cases, the public interest and its subset - conservation interest - should coincide, sometimes a finely balanced set of conservation risks and benefits may be tipped one way by other interests such as agriculture or public health.

Where information is insufficient to determine whether a specific new organism proposal could lead to the introduction of a new weed or pest, DOC will generally adhere to the precautionary principle and advise that approval is against the interests of conservation. If, however, the proposal is for a biocontrol agent that may alleviate a current environmental problem then this traditional application of the principle may not be in the interests of conservation, and a weighing of the costs and benefits of doing nothing as against doing something is more appropriate.

THE RISK ANALYSIS APPROACH

The paper looks at standard issues and issues specific to certain types of proposal to gauge whether each proposal is in the interests of conservation.

1. Is it a new organism?

One potential way that harmful new organisms can be introduced to New Zealand is mistaken identity, i.e. new organisms are allowed past the border if they are considered to be the same as or mistaken for a species that is already here.

Questions about whether an organism is a new species or not can be controversial. For example, in 1996 the Ministry of Agriculture (MAF) (ERMA's predecessor as decision-making authority) decided Bengal cats were merely a breed of the domestic cat (*Felis catus*) and not a new species and so allowed their importation. Because Bengal cats were a hybrid animal, involving a cross between *Felis catus* and a different species of cat from Asia, known as the Asian Leopard Cat (*Felis bengalis*), DOC considered these cats to be a new organism requiring an importation impact assessment before release could be contemplated. The matter was never resolved, and Bengal cats remain in New Zealand to this day. Whether DOC's and other's concerns about their potential to cause greater harm than *Felis catus* are warranted or not is unknown because no importation impact assessment has ever been carried out to test anecdotal reports that the cats are more effective predators. It is

interesting to note, however, that anyone seeking to bring in another Bengal cat-like hybrid will need ERMA approval. ERMA has made it clear that all such hybrids will be considered new organisms requiring an importation impact assessment (ERMA 1998).

In advising ERMA, DOC considers that where an organism has been classified as belonging to a species with no representatives in New Zealand, or where it has been subject to genetic modification, there can be no argument that it is new. Therefore, approval from ERMA is required before importation.

The less clear-cut cases involve organisms that are potentially different subspecies, infrasubspecies, varieties, strains or cultivars of species already in the country. Organisms in these categories are explicitly included in the HSNO Act's definition of new organisms, provided the organism in question has been deemed in regulations made under section 140 as a "risk species" capable of adverse effects on people or the environment. These subspecies may possess different qualities than their New Zealand relatives which make them less suitable for importation. Importers sometimes believe such organisms are not new and try to bring them past border control without approval from ERMA. In such cases, MAF's border control agency has agreed to work closely with ERMA and DOC in deciding whether such borderline organisms require assessment as new organisms.

DOC's advice regarding the status of an organism will depend on the reasons for its classification as a different subspecies, infrasubspecies, variety, strain or cultivar. If the classification occurs because the subspecies possesses qualities that represent a different or greater threat to conservation, such as more effective predation, it should be regarded as new. If there is any doubt about this DOC will use the precautionary principle and recommend that the organism be assessed as new.

It is important to ensure that all resident species in New Zealand with potentially harmful subspecific relatives overseas are classified as "risk species" under s. 140. Without this classification, such harmful subspecific relatives would have unrestricted entry as organisms that are not new. With the classification these relatives may be regarded as new organisms requiring approval from ERMA. If new species arise as candidates for classification as "risk species" DOC will request that the responsible Minister (the Minister of Agriculture) arrange the appropriate Order-in-Council.

2. Is it safe to bring into containment?

Many of the new organism applications ERMA receives are applications to import new organisms into containment or develop them in containment using genetic modification. The Authority is required by s. 53 of the HSNO Act to notify DOC whenever it receives such an application and by section 58 must have particular regard to DOC's subsequent submissions.

DOC looks at two broad questions when advising on containment applications. The first is the likelihood that the organism will escape containment. The second is the likely environmental consequences of such an escape. To advise that a containment application should be approved DOC will need to be satisfied that the risk to the environment is very low and is outweighed by the potential benefits of the exercise. The low estimate of risk may arise from either very secure containment, negligible chance of escape, or negligible risk of environmental damage should escape occur.

2(a). Negligible risk of escape

Under section 40(2) of the HSNO Act the applicant must include details of the containment system. For DOC to be satisfied that the risk of escape is negligible, the containment system must not only be secure for the present, but contain mechanisms to ensure it is secure for the duration of the organism's stay. This would require ERMA to enforce the relevant containment provisions under schedule three of the HSNO Act. Additionally, it requires the containment facility to have been approved by MAF under s. 39(3) of the Biosecurity Act, which means it has complied with standards approved by MAF in consultation with DOC under s. 39(1) of the Biosecurity Act. If there are particular concerns with a containment application and the maintenance over time of its security, DOC will review the suitability of the standards that will govern the containment facility. Most of these standards are held on file by the new organisms officer.

2(b). Low risk of environmental damage

If the level of containment matches the above minimum requirements then an inquiry need not be as detailed as the similar analysis or "Importation Impact Assessment" required if an organism is intended to be deliberately released. Unless the organism has an obvious potential to inflict significant harm on the environment DOC will be content to rely on the containment measures to negate risk.

If the level of containment is less than the minimum requirements above then a low risk of environmental damage becomes extremely important. Generally there must be convincing evidence that the organism is unable to persist in the New Zealand environment, or would be easily rounded up if escape did occur. Otherwise DOC will recommend that the application be treated as a release and that the applicant make the appropriate application.

2(c). Advice for upcoming trials

A good time to offer advice is when applications to import into containment are made in order to enable further trials to determine an organism's suitability for release. DOC will consult the appropriate assessment procedures under section 3 to determine what information to give prospective trialists.

3. Is it safe to release?

The other type of new organism application received by ERMA is to release into the environment. DOC's assessment of the suitability of a particular application to release will depend on what category the organism falls into. Depending on whether it is a new invertebrate, plant, micro-organism, vertebrate, or a genetically modified organism a number of different factors will be taken into account. Furthermore, the purpose for which it is to be released can be relevant, i.e. control of a weed or pest, as a new crop, or some other purpose.

3(a). Invertebrates for the control of weeds

The use of invertebrates as weed biocontrol agents is a common motivation for new organism applications. DOC has part-funded a number of these projects in the past (e.g. a sawfly to control old man's beard) and will continue to do so. An obvious check that should not be overlooked is to find out whether control of the plant target is in the interests of conservation. A plant might be a conservation weed that excludes and outcompetes native plants under some conditions while

performing valuable functions such as erosion control, or shelter for native seedlings and vulnerable fauna in other places (e.g. gorse). Likewise, a plant might interfere with agriculture while being useful for conservation (or even being a valued native itself - for example manuka - in which case any kind of biological control is unacceptable). In such cases the conservation benefits and costs of controlling the plant in question will be weighed carefully.

3(a)(i). Risk of Direct Non-Target Impacts

Generally insects in this category will be exclusively herbivorous, but this still needs to be confirmed by the applicant. If they aren't, then the assessment procedure for category B (invertebrates for the control of invertebrate pests) will also be followed.

Native Plants Acting as Non-Target Hosts

The main direct risk, therefore, is simply that the agent will utilise important plants other than the target weed. The applicant's importation impact assessment should contain host specificity information and/or tests to determine what taxonomic range of plants can act as hosts for the agent. Ideally, this is determined by studies of the agent in the field, but because such studies are difficult and expensive it is usually left to testing referred to in the literature or carried out by the applicant. Fortunately, invertebrates generally do have a host range that can be described taxonomically. Invertebrates use certain chemical and morphological cues to choose their host (Beck 1965, David & Gardiner 1966, Currie 1932, De Wilde & Schoonhoven 1969, Jermy 1966, Thorsteinson 1960, Verschaffelt 1910, Zwolfer 1969), and these cues are common to particular groupings of related plants (Swain, 1963). Once the limits of the agent's host group have been determined, any plants outside it can generally be considered safe. There are some exceptions to this general rule, however, where plants outside a determined limit will not necessarily be safe. Wapshere (1974) identifies three exceptions involving:

(i) unrelated plants lacking the same particular chemical inhibitors;

(ii) an agent having two unrelated alternate hosts for different stages of its life cycle;

(iii) unrelated plants possessing the same chemical stimulants.

Host specificity testing must be designed to take these exceptions into account and methods for this are described in the next section.

Another factor to bear in mind with host specificity testing is that, even if an agent comes through testing as host specific, it is possible over time for evolutionary pressure to evolve new races that can exploit new host species. Ginzburg (1991) records the case of *Chrysolina quadrigemina* in northern California, which provided control of *Hypericum perforatum* L. but a number of years later began to impact on *H. calycinum,* a cogeneric plant used for groundcover. It was suggested that this was the result of the evolution of a new race of *Chrysolina.* This possibility for evolution makes it important for closely related natives to have some sort of a phylogenetic buffer zone between them and the edge of the agent's host range.

Check that all relevant plants have been tested

The testing regime used by most weed biocontrol practitioners in New Zealand is based on the centrifrugal phylogenetic testing method as described in a paper by Wapshere (1974). DOC supports the use of this testing and will check for the applicant's adherence to this regime as set out below.

The host specificity tests need to test taxonomically related plants in order to determine the range of plants able to be utilised by the agent. Because weeds are generally exotic a lot of the most closely related plants will also be exotic, and consultation of the relevant flora from the weed's native range may be a good idea. This may not be absolutely necessary, however, because a lot of naturalised exotics occur in New Zealand, and they are well documented in the *Flora of New Zealand Series* (Appendix 2).

If the weed is a grass, identification of close relatives for testing becomes more difficult because the New Zealand grass flora is not yet finished. In the meantime, DOC uses information held on file on introduced and native grass genera kindly supplied by the authors of the new flora.

Test results should start with the most closely related examples (i.e. any plants in the same genus) and move outwards through related tribes and even families, depending on what initial results are obtained. As host suitability levels drop off to zero, the outer extent of the agent's feeding range is determined. In other words, once negative results are received for plant relatives at one level of classification (e.g. family) it may be tentatively concluded that host status is restricted to members of the previous level of classification that received positive results (e.g. subfamily). Some confirmatory testing of plants beyond the determined limit of relatedness is then necessary to ensure that this limit is genuine. This confirmatory testing is essential, because it is possible for an agent to test negative for some representatives within a phylogenetic group (e.g. a genus) and then positive for closely related representatives in a wider group (e.g. tribe). The plants tested to provide this confirmation should include:

(i) species that have been recorded as having the agent present on them;
(ii) representatives of related New Zealand natives; and
(iii) species that are hosts of close relatives of the agent in question.

Check that the tests are adequate to determine the host range

After determining whether the applicant has tested the appropriate species, it needs to be determined whether the right type of tests have been conducted. A number of different kinds of tests are available. The most reliable tests involve presenting agents with test plants and allowing them to behave normally under field conditions and seeing which plants they are able to utilise. However, owing to the need for containment or limited supplies of the agent these kinds of tests are usually not practicable and less natural tests must suffice. Fortunately, Wapshere (1989) found that such less natural tests tend to exaggerate an agent's host range and give false positives rather than indicating more worrisome false negatives (though there is an exception to this - see the next paragraph).

From the perspective of ensuring host specificity and negligible non target impact, DOC will generally be satisfied with relatively artificial tests where larvae (and any other stages with the potential to inflict feeding damage) are placed directly onto the test plant in a container. It is up to the applicant to conduct more realistic tests (i.e. seeing if adults will lay eggs and following those eggs through to adulthood) if the earlier tests indicate a wide host range that precludes release. Note that subsequent 'realistic' tests that can rule out any kind of role for an agent as a full host do not necessarily rule out the risk of some kind of direct feeding damage. Where, for example, positive feeding tests have been received for a test plant, but later tests show that the agent can't lay eggs on the plant so can't utilise it as a host, potential still exists for the test plant to suffer 'bystander' damage, i.e. agents reared on regular host populations growing in the vicinity spilling over and feeding on the test plant.

The exception to the rule that artificial tests exaggerate the host range involves the use of 'no choice' tests. As the name suggests 'no choice' tests entail putting the agent in a container with only the test plant so it has no choice in that its only chance of survival and reproduction is to utilise this plant. This usually tends to exaggerate the host range by forcing the agent to make 'last ditch' attempts to feed or oviposit (lay eggs). It may also underestimate the host range in circumstances where the presence of a regular host fulfils an agent's need in order to lay (e.g. a mating site, a feeding compound, a behavioural cue). In such cases, an agent may feed or lay more widely in the presence of its regular host than in its absence (as was documented by Hill et al. (1996) for *Phytomyza vitalba* - an agent to control old man's beard in New Zealand). This highlights the need for 'choice' tests, where the agent is placed in a container with the test plant plus its preferred host. 'Choice' tests are usually used by the applicant to invalidate possibly false positives given by the 'no choice' tests, however, they are also necessary to double check for false negatives. If positive results show up in such tests and not in the 'no choice' tests it doesn't mean the plant in question is a full independent host, but it leaves open the possibility that it could function as a host when growing in the vicinity of populations of the regular host.

Risk of indirect non-target impacts

The risk here is that the agent's presence in New Zealand ecosystems will change those systems to make them less favourable for conservation.

For example, the agent may serve as prey for resident predators and parasitoids, boosting their numbers, and then becoming unavailable as a prey item through some cyclic population bust, overwintering, or other such event. Deprived of the new population that was sustaining them and their population boom, higher numbers of the agent's former predators would be unleashed upon other parts of the fauna. All that can done here to determine the likelihood of such a scenario is to investigate whether the appropriate predators and parasitoids that can affect both the agent and native fauna exist, and whether the agent is likely to suddenly decline or become unavailable.

The permutations for such indirect effects are endless and most of them seem unlikely. It is unlikely that quantitative predictive information can ever be obtained for a new ecosystem. Nobody predicted that the introduction of the rabbit killing *myxoma* virus in Britain would cause the extinction of an insect. That was the fate of the large blue butterfly, *Maculina arion,* as reported by Simberloff (1996). The lack of rabbits resulted in a lack of production of underground nests by ants which required the now scarce open rabbit-grazed sites. The butterfly needed these nests as larval development sites and this very conspicuous insect perished without them. Whether any less conspicuous insects met similar fates is not known. Thus questions about indirect effects are valid and need to be asked, and a judgement made as to whether they constitute a significant risk.

Assessing the benefits of the weed biocontrol agent

Because any kind of addition to New Zealand's insect fauna involves some risk the potential benefit from introduction must be established. Often, however, the weed targeted for control is an agricultural weed only and in such cases it can only be concluded that introduction is not in the interests of conservation. ERMA will then decide whether other interests override conservation. If the target is a conservation weed then there may be conservation benefit in its control and some cost-benefit analysis may be done.

Firstly, an assessment is needed of the chances of the agent being a success as a weed biocontrol and, if so, how much of a success. This is notoriously difficult as scientists researching the theory and practice of weed biocontrol remain a long way from developing methods for predicting which insects are likely to be effective biocontrol agents. The best indicator is observational evidence that shows suppression of the target in its native habitat.

Generally, feeding trials are not considered to be a reliable indicator of the kind of damage a weed is likely to sustain in the field because the many variables of field conditions will affect the density the agent may attain. Nevertheless, DOC considers that some sort of feeding trials in which ideal feeding conditions were provided for the agent would be useful in that they would at least rule out some agents as good biocontrol options. If an agent cannot suppress the weed under ideal conditions then it certainly won't in the field. Therefore DOC will encourage applicants to consider this kind of feeding trial. Often these trials are carried out in an de facto manner while populations of the agent are reared. All the applicant needs to do is observe and report the results.

In the absence of direct observational or experimental evidence of the agent's likelihood of success, certain characteristics of the agent can be useful indicators, though should not be considered hard and fast rules. Agents that attack roots may be more damaging, while those that attack stems, leaves, and reproductives may be steadily less effective. A high intrinsic rate of increase can be important. Agents that are highly parasitised and diseased in their native ranges may be more effective when released in New Zealand free of these restrictions.

When investigating the chances of success for a biocontrol agent, first DOC will take into account the possible synergy of the invertebrate interacting with other biocontrol agents within an array of agents targeted at the weed.

Secondly, an assessment of how damaging the target weed is for conservation, and therefore how useful a successful control would be, is necessary in assessing the overall benefits of release. In making this assessment, the general literature and weed staff in conservancies will be consulted.

Comparison of risks and benefits

Once the probable host range is known, and the chance of indirect non-target impact has been determined, this may be weighed against the potential benefit of a successful biocontrol for the weed.

If there are likely to be direct feeding impacts on other plants, the conservation benefit of those plants will be assessed. If they were native then the benefit of controlling the weed would have to be significant indeed in order to justify putting part of the native flora at risk. If they are exotic they still may have conservation benefits and the same checks that were undertaken in ensuring the weed had no conservation value should be repeated for a vulnerable exotic.

3(b). Invertebrates for the control of invertebrates

Invertebrates are also imported to improve natural control of pest invertebrates by predation or parasitism. As was the case with weed biocontrol, it is necessary to assess whether control of the pest in question is really in the interests of conservation, or whether it performs any useful functions for conservation. For example, the target invertebrate might actually help to control a conservation weed, or it might be a native itself - in which case DOC will usually oppose any control attempt.

Risk of direct non-target impact

As with weed biocontrol, the biggest concern is that the agent will attack other hosts. The testing regimes used for weed biocontrol agents are much more difficult to apply for invertebrate biocontrol agents. While weed biocontrol agent host specificity testing is detrimentally affected by the agent's artificial confinement in lab conditions, the confinement of the plant hosts is not too much of a disruption to accuracy. Host specificity testing of invertebrate biocontrol agents is doubly confounded by both the host and the agent being forced to perform under disruptive laboratory conditions. Furthermore, entomophagous invertebrates are unlikely to be specific to one host. Such specific feeders are rare. These factors mean that laboratory testing alone is often not enough and a variety of field observations and other methods are also required. Nevertheless and as with phytophagous invertebrates, the artificiality of laboratory tests does generally over-estimate entomophagous host range (Goldson 1990) so their unreliability is not going to lead to unsafe agents being released. The need for other methods is useful for biocontrol proponents wanting to show that an agent with a wide laboratory host range really is safe in the field.

Check that all relevant invertebrates have been tested

While approximately 80 percent of the 2300-2470 native New Zealand plant species have been described and classified (P.J. de Lange pers. comm., 1997), less than half of New Zealand's estimated 25,000 native insects have been described and many have not yet been discovered (Barratt 1997). The situation for other invertebrates is similar.

So, while the taxonomic range of a predator or parasitoid can still be determined by phylogenetic centrifrugal testing, this method has more limitations with entomophagous invertebrates when compared to phytophagous invertebrates. If introductions proceed on the basis that there are no important invertebrates known to be within the agent's host range an unknown or undescribed native invertebrate within a potential agent's host range would be put at risk.

Having said this, the number of invertebrates to be tested can be reduced dramatically if the field behaviour and/or life history of the agent obviously precludes it from utilising on a number of hosts that might otherwise be potentially suitable. For example, some parasitoids infiltrate hives and lay their eggs in the cells of developing larvae (e.g. *Sphecophaga vesparum burra* - Harris 1996). Insects such as these only need to be tested against hive dwellers. Similarly, other invertebrates live in different climates, geographical areas, or discrete parts of the ecosystem (separated in space or time) so don't need to be tested (Goldson 1996).

With these caveats in mind, the first task is the determination of the classification of the target invertebrate pest. This should already have been carried out by the applicant and may be reliable. If the classification is unreliable it becomes necessary to consult an insect fauna from the pest's home country, or one of the invertebrate specialists on DOC's new organisms consultation group (see Appendix 1).

The next task is to check whether the agent's host range has been accurately determined. As with phytophagous species, the best information is observational studies of the agent's behaviour in its native environment, but because this is not usually available, testing enough of the target pest's related species becomes the prime method to accurately determine host range. The closest relatives are likely to be in the pest's home country so again, an appropriate insect flora or expert needs to be consulted. The *Fauna of New Zealand Series* (Appendix 2) is useful in determining what native species are related and need to be tested. It consists

of some 37 volumes and deals with most groups. Also useful is a catalogue of New Zealand insects and their host plants (Spiller and Wise, 1982) which can further emphasise what native insects need to be tested. This is not just because they are taxonomically related, but because they utilise the same kinds of plants and habitats as the pest and hence are likely to come into contact with the pest's control agent. Another useful resource is the list of publications in Ramsay's *Guide to New Zealand Entomology* (Ramsay and Singh 1982).

Check that tests are adequate to determine the host range

Tests must expose the host-selecting-stages of the pest control agent to test invertebrates in their susceptible stage. For example, if the agent is a parasitoid with an adult stage that deposits its eggs inside a larval host then the test must involve those appropriate stages.

Risk of indirect non-target impacts

The risk here is similar to that described for indirect effects of weed biocontrol agents. Native species may be disadvantaged by changes in the ecosystem brought about by the new resident. Once again, the permutations are endless and our ability to predict quantitative outcomes is poor.

Assessing the benefits to conservation of the invertebrate biocontrol agent

It is difficult to know whether a pest control agent is likely to significantly affect the pest until it is actually released. However, there are some useful indicators. Information on the rate of predation or parasitism in country of origin is useful to know. Though that same rate is not necessarily going to be repeated here, it does give some idea as to the agent's potential. If it accounts for greater than negligible mortality in pest populations then it shows some promise. Another useful indicator is the stage attacked by the agent. If it customarily attacks adults of prime reproductive age then it shows more promise, while attacks on juveniles or eggs are less significant because many of these would be unlikely to reach reproductive age.

Comparison of risks and benefits

Generally, if an application puts any part of the native fauna at more than negligible risk by the introduction, then it is judged not to be in the interests of conservation. If the project has significant potential to combat a severe conservation problem then a greater than negligible conservation risk may be accepted as the lesser of two evils.

3(c). *Introduction of plants*

Applicants may seek to introduce plants as new crops, or ornamentals.

Risk of non-target impact

The obvious risk is that the plants will invade valuable ecosytems and become weeds. Until such time as ERMA decides to change the new plant assessment procedure used by its predecessor (the Minister of Agriculture and his or her delegates), DOC restricts most of its input into these applications to periodic review of the Weed Risk Assessment Model administered by Landcare. This model uses the behaviour of plant families, genera and species both overseas and in New Zealand to try and predict how a plant will behave here. Where the model has insufficient information to predict whether a plant is likely to become a weed, DOC will recommend the application is not in the interests of conservation.

The risk posed by new varieties or genetic stock of naturalised exotic species is considered back in section 1 where members of the same species can be considered new organisms as long as the New Zealand resident species is classified as a risk species.

3(d). Introduction of micro-organisms (including bacteria, viruses, prions and microscopic fungi)

These organisms may be pathogens intended for use against a pest population, or they could be micro-organisms for research or industrial purposes.

Pathogens/Obligate Parasites

These are micro-organisms which are dependent on a host for survival and reproduction and cannot exist outside the host for extended periods.

Appropriateness of target

If the proposed new organism is a biocontrol agent it is necessary to investigate whether the target has useful functions and if its control is in the interests of conservation.

Host specificity

If the organism is a pathogen and an obligate parasite the main concern is that it will not infect anything else important. DOC does not really have sufficient expertise in pathology to assess this so will be heavily reliant on the accuracy and completeness of the applicant's information. In most cases, there should be expertise enough to assess whether this information establishes the level of host-specificity it claims, but if the validity and accuracy of the information itself needs to be questioned, outside expertise will have to be brought in. This would require diversion of conservation funds or some sort of cost recovery, and unless either of these actions is feasible, the authenticity of the applicant's information cannot be checked. Any subsequent departmental recommendation would have to be made with the proviso that the decision-maker independently satisfies itself of this authenticity.

Risk of indirect non-target impacts

This risk is the same as that identified in the other sections - namely, that through reduction of the target's population density, or some other ecological effect, the agent's presence will alter ecosystems to make them less favourable for conservation.

There are endless permutations for such indirect effects, but two of the main ones to watch for are prey switching and predator guild effects. These were major concerns with the importation of the lethal rabbit calicivirus disease.

Prey switching results when the pathogen reduces the density of its target so dramatically that any predators that usually rely on the target must switch their attentions to other, possibly native, prey.

Predator guild effects occur when the pathogen affects the prey item of a larger predator that also preys on other smaller predators. When the pathogen afflicted prey population decreases, the larger predator's population will eventually decline, reducing its predation pressure on the smaller predators and allowing them to increase in numbers. This changed ratio of small to large predators results in a different pattern of predation which, depending on the regular predation behaviour of the smaller predators, may result in a higher predation pressure on native fauna.

Free living micro-organisms

The main concern is to ensure such organisms will not become micro-scopic pests or weeds. Not much is known here so unless compelling evidence is presented about such an introduction's inherent ecological safety DOC will not support such applications in the interests of conservation.

3(e). *Introduction of vertebrates*

Applicants may want to bring in vertebrates for reasons ranging from agriculture to pure novelty value (commercial or otherwise).

Vertebrates are almost always unsuitable as biological control agents because their browsing or predation is too general and puts too many non-target plants and animals at risk.

Accordingly, any introductions are usually intended to be at least semi-contained, because the animals are of no use if they are wild. DOC does not welcome any more naturalised exotic vertebrates in New Zealand so a pre-requisite of it supporting any application would be that the introduction's semi-contained status could be maintained. This means either:

(i) the animal should be shown to be unable to establish in New Zealand or

(ii) the animal should be large and obvious enough to be rounded up easily if individuals did escape.

Otherwise the potential for a new vertebrate pest exists and, barring exceptional circumstances, DOC will oppose importation.

3(f). *Introduction of genetically modified organisms*

Many of the concerns associated with the introduction of genetically modified organisms (GMOs) are the same as for any new organism. The concern with plant GMOs is their potential to become environmental weeds, and the issue for animals and micro-organisms is their potential as pests or harmful pathogens. With GMOs, however, there are a few additional considerations that DOC will use in coming up with its recommendations. These are dealt with below with respect to the various types of new organism applications likely to be heard in the future. Other types will almost certainly arise and DOC will have to deal with these on their own merits.

Supercrops becoming superweeds

The concern here is that crops engineered for superior yield and quality may themselves become weeds (or worse weeds) following the modification. If the new genotype involves removing limiting factors through improved growth characteristics, or some kind of insect, disease or herbicide tolerance then its potential for weediness is undoubtedly enhanced. If the plant is already a conservation weed in New Zealand in its unmodified form then DOC will oppose release of the more dangerous variety as contrary to the interests of conservation. If the plant is naturalised in New Zealand and is not currently a conservation weed then some judgement will need to be made as to whether pest pressure, disease or low growth rate are important as factors in limiting its weed potential. If the plant isn't naturalised in New Zealand then, once the regular new plant assessment procedure had been undertaken (see section 3(c)), the same judgement will need to be made.

Modified crops passing traits to potential weeds

Another concern is that the traits of a genetically modified crop plant will be transferred to other weedy or potentially weedy species in New Zealand. The simplest way this could happen is through hybridisation between the GMO and another plant following a successful pollination. The hybridisation range of the GMO needs to be determined through testing of close relatives to ensure that there are no co-existing species that could form a dangerous new hybrid with the GMO. Test plants should be chosen according to the centrifrugal phylogenetic testing method described in section 1(a).

Some enquiry into the likelihood of gene transfer from the GMO to other plants through the process of transduction should also be made. Transduction is the process by which viruses carry some of the DNA from their previous host to a new host, and this should still be investigated even though the chances that the relevant portion of DNA will be transferred appear slim.

Pesticide resistance

Another concern is specifically related to pest-resistant crops. As these crops achieve their pest resistance by producing a pesticide in their leaves that kills their pest, they amount to a constant dosing of pest populations of the kind that creates a selection pressure for resistance among pests. Accordingly, DOC will want to see effective resistance management strategies before any release of pesticide resistant crops. These strategies need to investigate planting of non-modified crop plants as pest refugia, where populations of the pest can breed and swamp any emergence of pesticide resistance in the rest of the population. It is also necessary to ensure that the dosage received by pests when they eat the modified crop is sufficiently potent to kill almost all pests, so that the resistant minority are a minority indeed and can be swamped by non-resistant types from the refugia.

International consultation

DOC will encourage ERMA to consult internationally with its decision-making counterparts overseas. This is because, like all organisms, GMOs do not respect political boundaries and are likely to spread to other countries once introduced here. Unlike other organisms, however, a GMO does not occur anywhere until released, so a release potentially affects foreign countries to a much greater extent than the release of other new organisms if the release is a "world debut". DOC will therefore advocate international co-operation on GMO releases in order to respect the interests of other states and encourage other states to respect the interests of New Zealand.

CONCLUSION

Assessing the merits of new organism proposals will always be an evolving doctrine. This paper presents a snapshot of the current principles used by DOC in making such assessments and these principles will undoubtedly change as new information is learned.

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APPENDIX 1

New organisms consultation group

Chris Green	invertebrates
Rod Hay	birds
Brian Lloyd	bats
Graeme Loh	reptiles
Ian McFadden	rodents
Colin Miskelly	birds
Elaine Murphy	mammalian predators, general predator-prey (relationship implications)
Don Newman	reptiles, frogs
Colin O'Donnell	birds
Brian Patrick	invertebrates (Otago Museum)
Marcus Simons	freshwater environments
Susan Timmins	weeds, native flora
Eduardo Villouta	marine environments
Carol West	weeds, native flora

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Predator visits to poison baits placed in stations and the value of baits as a tool to control predators of black stilts

Richard F. Maloney and Dave P. Murray

Department of Conservation, Twizel Area Office, Private Bag, Twizel.

SUMMARY

- Two types of 1080 baits in pellet form ("Landcare" and "Bait-tek" baits) were placed in plastic bait stations or on the ground in three trials alongside the Tekapo and Pukaki Rivers, Mackenzie Basin, South Canterbury.
- Bait loss was regularly recorded and some stations were videoed to record visits by animals. Follow-up leg-hold trapping was carried out after each trial to determine whether predators were present in the area following the poisoning operation.
- In Trial 1, 101 plastic stations were baited with either Landcare or Bait-tek baits for 52 days. The rate of removal of baits by predators was higher for Landcare baits (9.95 baits taken/100 station nights) compared to Bait-tek baits (2.38 baits/100 station nights).
- In total, 280 station nights were videoed on stations with Landcare bait and 297 station nights on Bait-tek stations for Trials 1 and 2 combined. The number of animals recorded on film at stations was highest for Landcare baits (21.4 and 17.2 events/100 station nights for Landcare and Bait-tek, respectively), mainly because more possums ate Landcare bait. Of all videoed events, only 3 of 21 cat, 1 of 15 ferret, 5 of 31 possum, and 6 of 41 hedgehog events resulted in the animal eating bait. Cats would often investigate the bait closely, put their head inside the container, and even mouth baits, but usually did not eat the bait.
- In a third trial, Bait-tek bait was either placed on the ground (109 video nights) or placed in stations (94 video nights). More events were recorded on ground-placed bait (28 events compared to 17 events in stations), and more visits resulted in animals eating bait (15 events compared to 3 at stations). Notably, baits were eaten in 8 of 12 cat visits to ground sites, but only 2 of 7 visits to plastic stations.
- Although predator densities were unknown throughout the trials, all species recorded at stations were also caught in large numbers in leg-hold trapping after each poison trial. Therefore, poison bait stations were not successful in lowering predator densities to low levels.

- We consider that the plastic bait stations and Landcare and Bait-tek baits used here have limited application as a stand alone method for controlling predators of black stilts, because few predators visited bait stations, and even fewer ate the baits.

INTRODUCTION

Predation of eggs and chicks of black stilts (*Himantopus novaezelandiae*) is limiting the number of young available for recruitment into the population. Fledging rates may be as low as 1% of total egg production (Pierce 1986, Pierce 1996), and as many as 77% of all chicks hatched may be taken by predators (Reed 1998, Saunders et al., 1996). An up-to-date review of the survival of black stilt chicks over the last 15 years is underway. The review, coupled with detailed 24-hour video monitoring of nests and of pairs with chicks, will improve the ability of future predator control programmes to target key predators at critical stages in the black stilt breeding cycle. However, in the absence of detailed evidence as to which predator species may be responsible for black stilt egg and chick losses, we consider that a broad approach to controlling all members of the predator guild will enhance protection of eggs and chicks of black stilts.

Mammalian predators of black stilts (ferrets *Mustelia furo*, cats *Felis catus*, hedgehogs *Erinaneus europaeus*, stoats *Mustelia erminea*, rats *Rattus* spp.) have traditionally been controlled by exclusion, poisoning, or trapping. Exclusion by building predator-deterrent fences has been used to protect small discrete areas of wetland habitat that may be used by black stilts for breeding. Poisoning, using eggs injected with 1080, has been used inside protected areas where public access can be controlled, but is not suitable for long-term control over large areas of public land. Trapping is a direct method of killing predators that has been very effective (Keedwell 1998, Reed 1998), but has high operational costs for relatively short-term protection. Other methods of control that provide longer-term control with less input need to be investigated.

Ideally, a control operation should have low to medium start-up costs, be very effective at reducing predator numbers, provide continued protection over a long period of time, and require little day-to-day maintenance. One method that may meet all of these criteria is poison bait stations. Fixed stations could be placed in many localities throughout an area requiring protection and be baited with an attractant laced with poison. Predators would visit these stations and take a small amount of the bait on offer - the remainder of the bait being available for future visits by other predators in the area.

Research on the attractiveness and effectiveness of baits for cats is well advanced in pen trials (e.g., Eason et al., 1992a, Eason et al., 1992b, Morgan et al., 1994), and controlled field trials in Australia and in forest situations in New Zealand have been undertaken (e.g. Eason et al., 1992a, Friend & Alger 1993, Morgan et al. 1994). Poison baits are used specifically as a management tool in one New Zealand locality, to control cats at New Zealand dotterel (*Charadrius obscurus*) breeding sites on Stewart Island (J. Dowding pers. comm.). However, the predator-prey guild in black stilt areas in the Mackenzie Basin (cat and ferret-rabbit dominated) is quite different from that in forest situations (stoat - mouse and rat dominated), and that in Australia (cat and fox-marsupial). Therefore, further trials of baits and bait stations

in open riverbed and grassland habitats of the Mackenzie Basin are warranted. Here we report on a trial to test the attractiveness of poison bait stations and their effectiveness in controlling cats and other mammalian predators in the Mackenzie Basin. The goal is to determine whether poison bait stations are suitable as a method for protecting breeding black stilts and their offspring from predation. Using two types of bait, our objectives were:

(1) to record which predator species visit bait stations baited with two types of baits
(2) to measure proportion of visits to a station that results in bait being eaten
(3) to determine whether enough bait is eaten at a station to kill a predator after one visit
(4) to compare bait take from plastic stations with bait placed on the ground

METHODS

Baits and bait stations

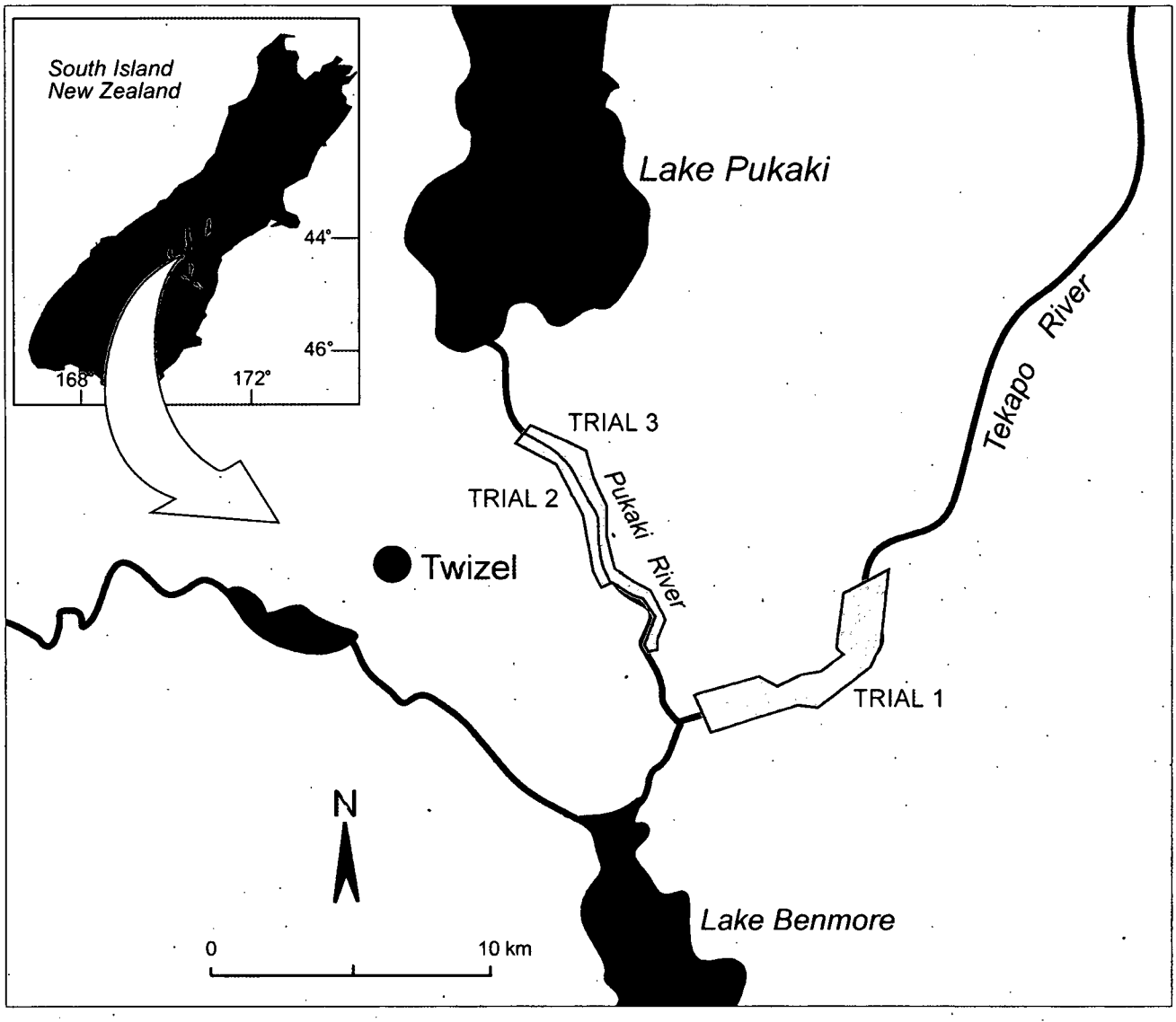
Bait stations were placed at regular intervals in the Lower Tekapo and Pukaki riverbeds in the winter of 1997, and in autumn of 1998. Stations were built from cut-off 4-l liver containers, and were side mounted 0.1 m above the ground on a metal stake. The container opening was approximately 200 mm x 200 mm in diameter. Containers sheltered bait from rain, and prevented baits from being scattered over large distances.

Two types of baits were compared. The baits were pellets produced by Bait-tek Ltd, USA, (henceforth "Bait-tek" bait, 0.106 % Sodium monofluoroacetate, 1080), and pellets developed in New Zealand by Landcare Research ("Landcare bait", 0.097% 1080). Bait-tek baits are 15 mm x 10 mm tubular pellets of regular size. Landcare baits are 25 mm x 10 mm solid cylindrical pellets and are more variable in size. The LD_{50} for 1080 for cats is 0.3 mg kg^{-1}, for possums 1.2 mg kg^{-1}, for rats 1.4 mg kg^{-1} (Hone and Mulligen 1982 in Haydock and Eason 1997), and for ferrets is 1.41 mg kg^{-1}. Therefore, ingestion rates of 1080 of about 1 mg for cats, 1.5 mg for ferrets, 0.3 mg for rats, and 3.6 mg for possums (*Trichosurus vulpecula*) are required.

Trial 1, 8 July – 28 August 1997

In 1997, 101 bait stations were placed at 100-m intervals along the true left and true right sides of the Lower Tekapo River (Figure 1). Landcare and Bait-tek bait was alternated among stations, thus there were 50 Bait-tek and 51 Landcare stations throughout the 1997 trial. Twenty baits were placed in each container, and bait stations were checked three times, after 16, 21, and 15 days. In stations where some baits were missing, the remaining baits were counted and all baits at the station replaced. Bait take was recorded as the number of baits missing per period. To identify the species of predator eating the baits, three bait stations at a time were randomly selected and monitored using three sets of 24-hour infra-red video surveillance. Video cameras were placed 1-2 m from the stations. Tapes were changed and viewed daily and all events recorded. An event was defined as the presence of a mammal or bird (excluding rabbits and hares) within the field of view of the camera (an arc of approximately 5 wide by 10 m deep in daylight, and 2 x 2 m at night). For each event, we recorded:

FIGURE 1: LOCATION OF POISON BAIT STATION TRIAL SITES IN THE TEKAPO RIVER (TRIAL 1, 1997) AND THE PUKAKI RIVER (TRIAL 2 AND 3, 1998).



(a) the species of animal
(b) the time of day or night
(c) the time spent in the area of the station
(d) behaviour in view of the container (ignore, approach, head in container, eat bait)
(e) the number of baits eaten (counted the following day).

All animals and behaviours could be clearly seen on the tapes. Copies of all events (Appendix 1) have been kept and are held by Lindsay Canham, DOC Video Library, Rotorua, and by DOC, Twizel Area Office.

Trial 2, 10 February – 9 April 1998

To increase sample sizes, a second trial (Trial 2) was initiated in 1998. In Trial 2, seven bait stations were placed 500 m apart on the true right side of the Pukaki Riverbed (Figure 1). Bait type was again alternated between Bait-tek and Landcare baits (initially three Bait-tek stations and four Landcare stations, followed by four Bait-tek and three Landcare stations, in 10 day cycles). A video camera and 24-hour recorder was placed at every bait station, with animal approaches (events) and bait take monitored and recorded as in stations videoed in 1997.

Trial 3, 27 April – 22 May 1998

In this trial five plastic bait stations (as in Trials 1 & 2) were alternated with five "no station" bait placements to compare bait take from containers to sites with no containers. In the "no station" sites baits were placed directly on the ground. All 10 sites and cameras were placed 500 m apart on the true left side of the Pukaki River (Figure 1). To increase sample sizes only one bait was used. Bait-tek bait was chosen because preliminary analyses of the number of events at Landcare and Bait-tek bait stations in trials 1 and 2 were similar, but Bait-tek bait seemed to last longer in damp field conditions (see also Morgan et al., 1994).

Predator trapping

At the end of each trial, predator trapping using Victors leg-hold traps was undertaken to determine whether predators remained within the area of poison bait stations. All trapped predators were humanely killed, and each individual was recorded by trap site, species, and sex. Trap nights were corrected by subtracting 0.5 trap-nights for each sprung trap and for traps that caught animals.

RESULTS

Trial 1: Comparison of bait take in stations supplied with Bait-tek and Landcare baits

The 101 stations were set over 52 days from 8 July 1997 to 29 August 1997, a total of 5252 station nights (N = 2600 Bait-tek station nights and N = 2652 Landcare station nights). Bait was taken from 22 (44%) Landcare stations and 31 (62%) Bait-tek stations. Significantly more baits were taken from stations baited with Landcare bait (mean = 8.2 ± 6.37 s.d. baits taken per station, N = 264 baits, range 1-22), than from stations baited with Bait-tek bait (mean = 1.6 ± 1.15 baits taken, N = 62 baits, range = 0.5 - 5; Mann-Whitney U-test, U = 127.0, $P < 0.001$).
Of the baits that were taken, 51 % of Landcare and 59 % of Bait-tek baits were taken in the first 16 days that stations were set. After this period bait take declined then stabilized at 7.1 baits per 100 station days for Landcare bait, and 1.4 baits per 100 station days for Bait-tek bait (Table 1).

TABLE 1: NUMBER OF BAITS TAKEN PER PERIOD FROM 51 LANDCARE AND 50 BAIT-TEK BAIT STATIONS. VALUES IN PARENTHESES ARE BAIT TAKE PER 100 STATION DAYS.

PERIOD	LANDCARE	BAIT-TEK
1. 8 July - 24 July, 16 days	134 (16.4)	36.5 (4.6)
2. 24 July - 14 August, 21 days	76 (7.1)	15 (1.4)
3. 14 August - 29 August, 15 days	54 (7.1)	10.5 (1.4)
Total bait take	264 (9.95)	62 (2.38)

Trial 1 & 2: Events recorded at bait stations

In Trial 1 (1997) video cameras were placed at 12 stations (N = 5 stations with Bait-tek bait; N = 7 stations with Landcare bait; 8 % of all stations), and cameras were operated for 206 days and nights (3.9% total station nights, N = 108 nights at stations with Bait-tek baits; N = 98 nights at stations with Landcare baits).
In Trial 2 (1998), 371 video days and nights were recorded (N = 182 on stations with Landcare bait, N = 189 on stations with Bait-tek bait). Table 2 summarises the number and type of events recorded in Trials 1 and 2 combined.

TABLE 2: THE NUMBER AND TYPE OF EVENT RECORDED AT BAIT STATIONS SUPPLIED WITH LANDCARE OR BAIT-TEK POISONOUS BAITS. NUMBER OF VIDEO NIGHTS EXCLUDES NIGHTS WHERE CAMERAS WERE NOT OPERATIONAL.

EVENT TYPE	IGNORE STATION	APPROACH STATION	HEAD IN CONTAINER	EAT BAIT	TOTAL	EVENTS PER 100 VIDEO NIGHTS
BAIT-TEK (297 video nights)						
Cat	3	7	0	1	**11**	3.7
Ferret	0	9	1	0	**10**	3.4
Possum	0	4	5	1	**10**	3.4
Hedgehog	1	12	4	2	**19**	6.4
Mouse	0	1	0	0	**1**	0.3
Total	**4**	**33**	**10**	**4**	**51**	17.2
LANDCARE (280 video nights)						
Cat	0	4	4	2	**10**	3.6
Ferret	0	2	2	1	**5**	1.8
Possum	1	8	8	4	**21**	7.5
Hedgehog	1	16	1	4	**22**	7.9
Mouse	1	1	0	0	**2**	0.7
Total	**3**	**31**	**15**	**11**	**60**	21.4

There were 9 (4.2 events per 100 video nights) fewer events recorded at stations baited with Bait-tek compared to Landcare pellets, mainly because more possums were recorded at Landcare bait stations. Possum events also resulted in a greater number of events in the "head in container" and "eat bait" categories. In total, 4 of 51 (7.8 %) of events resulted in bait being taken at stations baited with Bait-tek pellets, whereas in 11 of 60 (18.3 %) of events at Landcare bait stations animals ate bait, but this difference was not significant (Fishers exact test, P = 0.18). Of the 18 events where some bait was eaten, 16 were of apparently lethal doses of one or more baits (the two events where less than one bait was eaten were at one Landcare and one Bait-tek station).

Events where cats ate baits were recorded from 1 of 11 and 2 of 10 of cat events for Bait-tek and Landcare bait, respectively (Table 2), and similar low take rates by ferrets were recorded (0 of 10, and 1 of 5 events for Bait-tek and Landcare baits). Ferrets were recorded near Bait-tek stations twice as often as at Landcare stations. Hedgehogs were recorded at bait stations regularly, made frequent approaches to the stations, and tried repeatedly to climb into the container. However, because of the height of the container off the ground, few hedgehogs were able to reach the bait. Similarly, mice were recorded in the vicinity of the station, but were unable to reach the bait. No rats or stoats were recorded at stations during these trials.

Trial 3: Comparison of bait stations with bait placed on the ground

More events were recorded at sites where bait was placed on the ground (28 events) compared to bait placed in stations (17 events; Table 3), and a greater proportion of visits to ground sites resulted in lethal doses of bait being eaten (39 %, 11 of 28) compared with 18 % (3 of 17) of events at stations. Generally, the number and type of events recorded at containers was similar to that recorded in

TABLE 3: THE NUMBER OF VIDEO NIGHTS AND THE NUMBER AND TYPE OF EVENT RECORDED IN TRIAL 3, AT STATIONS BAITED WITH BAIT-TEK BAIT IN CONTAINERS, OR WITH BAIT-TEK BAIT PLACED ON THE GROUND.

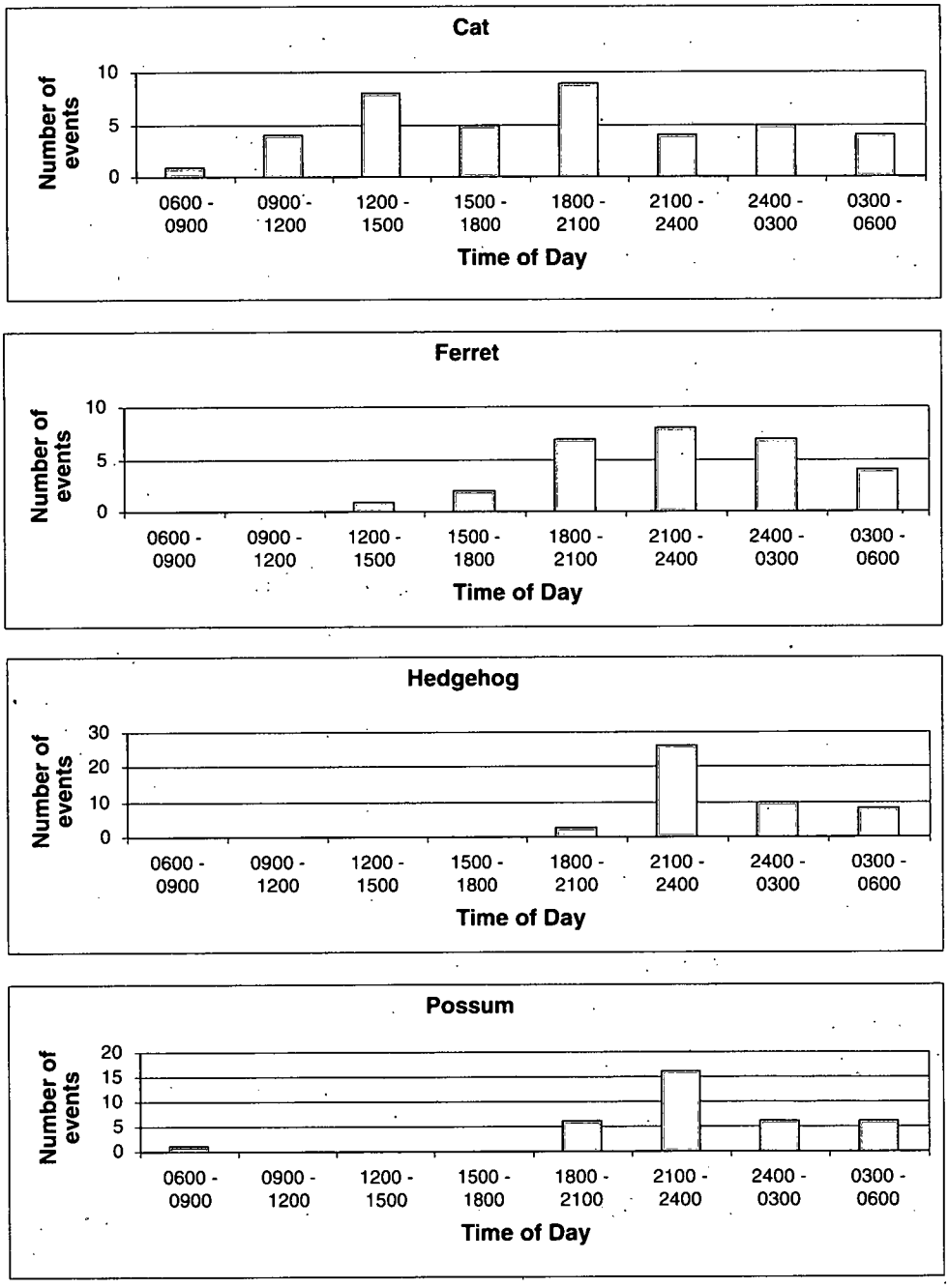
EVENT TYPE	IGNORE STATION	APPROACH STATION	HEAD IN CONTAINER	EAT BAIT	TOTAL	EVENTS PER 100 VIDEO NIGHTS
BAIT-TEK IN CONTAINER (94 video nights)						
Cat	2	1	2	2	7	7.4
Ferret	1	3	3	1	8	8.5
Possum	0	2	0	0	2	2.1
Hedgehog	0	0	0	0	0	0
Mouse	0	0	0	0	0	0
Total	**3**	**6**	**5**	**3**	**17**	18.1
BAIT-TEK ON GROUND (109 video nights)						
Cat	1	3	0	8	12	11.0
Ferret	0	4	1	1	6	5.5
Possum	0	1	1	0	2	1.8
Hedgehog	0	1	0	5	6	5.5
Mouse	0	0	1	1	2	1.8
Total	**1**	**9**	**3**	**15**	**28**	25.7

Trial 1 and 2 (above). However, the number of cat events at ground sites and the proportion of those events that resulted in bait being eaten (8 of 12 events, 67 %) was greater than at station sites (2 of 7 events, 29 %). Because sample sizes are small, there were no significant differences in the number of events recorded at stations compared to on the ground (Fishers Exact tests, $P > 0.05$). The number of station nights and events recorded are given in Table 3.

Daily timing of events recorded at bait stations

Hedgehogs and possums (always) and ferrets (mostly) visited bait stations in the hours of darkness, whereas cat visits tended to be well spread throughout the day and night (Figure 2).

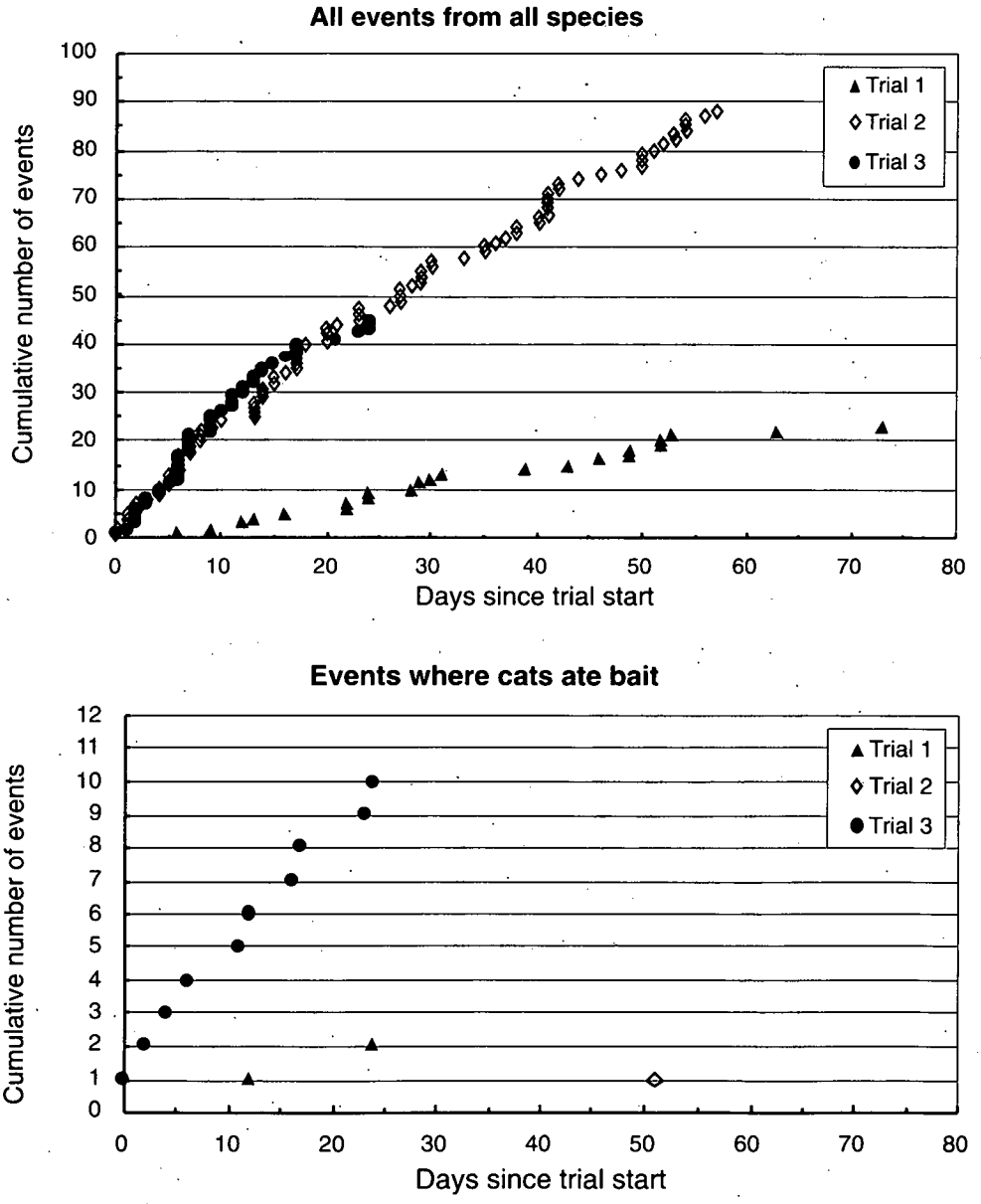
FIGURE 2: DAILY TIMING OF EVENTS RECORDED ON VIDEO TAPE AT POISON BAIT STATIONS FOR FOUR SPECIES (CATS, FERRETS, HEDGEHOGS, AND POSSUMS). FILMING WAS DONE FROM FEBRUARY TO JULY, THUS TIME OF SUNRISE AND SUNSET WILL VARY, AND ONLY THE TIME OF DAY IS PRESENTED HERE. FOR FURTHER DETAILS SEE APPENDIX 1.



Frequency of events over time and likely kill rate

In all three trials events were recorded throughout the period that stations were videoed, with no obvious decline in the frequency of events over time (Figure 3, and see Appendix 1). Between 27 and 32 animals ingested a potentially lethal dose (i.e., one or more baits) in the three trials, in a total of 780 video nights at 29 stations (N = 12, 7, 10 sites for Trials 1, 2, 3, respectively; data for both bait types combined), which equates to 3.4 deaths per 100 station nights.

FIGURE 3: CUMULATIVE FREQUENCY OF EVENTS RECORDED AT POISON BAIT STATIONS IN THREE TRIALS IN THE TEKAPO AND PUKAKI RIVERS IN 1997 AND 1998. (A) ALL EVENTS RECORDED FROM ALL SPECIES; (B) EVENTS WHERE CATS WERE RECORDED AT STATIONS.



The ratio between the number of baits taken and probable kills were similar among species. Cat events in which a cat ate at least one bait were recorded 11 times, but two occasions were on successive days and may have been the same individual. Therefore, a minimum of 9 cats were probably killed. Similarly, 3 of 3 ferrets, 4 of 5 possums and 10 of 11 hedgehogs were likely to have been killed in these trials.

Capture of predators following bait trials

Total numbers of animals caught per 100 trap nights was high (4.74 animals per 100 trap nights, excluding harriers) in poison station areas trapped immediately after each poison bait station trial. All predator species recorded on video were represented in post-poisoning trapping, although harriers were frequently caught in traps but were never recorded at bait stations (Table 4).

TABLE 4: NUMBERS OF PREDATORS CAUGHT, NUMBER OF CAPTURES PER 100 TRAP NIGHTS (ADJUSTED FOR CAPTURES AND SPRUNG TRAPS) IN VICTORS SOFT-JAWED TRAPS SET IN AND AROUND POISON BAIT STATION TRIAL SITES.

SPECIES	CAT	FERRET	POSSUM	HARRIER	HEDGEHOG	TOTAL
Trial 1 (2965.5 trap nights)						
Number of captures	11	35	13	23	80	**162**
No. per 100 trap nights	0.4	1.2	0.4	0.8	2.7	**5.46**
Trial 2 (410 trap nights)						
Number of captures	8	7	2	42	4	**63**
No. per 100 trap nights	2.0	1.7	0.4	10.2	0.9	**15.4**
Trial 3 (409 trap nights)						
Number of captures	4	6	4	49	0	**63**
No. per 100 trap nights	0.9	1.4	0.9	11.9	0	**15.4**

DISCUSSION

Our results suggest that poison bait stations baited with Landcare or Bait-tek pellets will be ineffective in controlling predator populations in the Mackenzie Basin. In Trial 1, the average number of baits taken per station was not high, and only 44-62 % of stations had bait taken from them, even though (as determined by leg-hold trapping immediately after poisoning) a large number of predators were probably living in the trial area at the time.

Low bait take was not because stations were not encountered. Most predator species were filmed in the vicinity of stations many times. Only harriers and stoats were not recorded, and because stoats were not caught in follow-up leg hold trapping they may have been absent or in very low densities in the study areas.

The videos revealed that low bait take occurred because animals that encountered a station did not eat bait. Two factors appeared to be important in determining bait take. First, because bait take was greater from sites on the ground compared with take from a plastic container, it is likely that the container deters animals from eating bait. Second, even when an animal put its head in the container and investigated the bait closely (and in some cases mouthed the bait), many of these animals chose not to eat bait. Therefore, the bait appears to be unattractive or inedible. A third factor, that animals were not hungry enough to take bait was not

directly investigated during this study. Predators could be expected to avoid taking artificial bait when the abundance of their usual prey was high (E. Murphy pers. comm.). Although we have no measure of prey abundance in this study, the timing of the bait trial over winter and autumn in 2 years should have been at the period when prey densities were at their lowest.

Encouragingly, when bait was eaten, it was nearly always eaten in sufficient quantities to kill the animal. Because animals were unmarked in this study it was not possible to identify individuals and we were unable to say whether the same individual predators may have encountered more than one station, or sampled bait more than once during the study. However, from the total number of animals caught in leg-hold traps at the end of each poison station trial, we can conclude that bait stations appear to be ineffective in controlling predator populations. Further work is needed here, using marked individuals with home ranges centered on bait stations to more closely examine the efficacy of stations in controlling predators.

Although Landcare baits were eaten more often, and in greater numbers than Bait-tek baits, a large proportion of Landcare baits were eaten by possums and hedgehogs. Few cats were recorded eating from plastic containers; those recorded tended to eat more bait from Landcare stations than from Bait-tek stations. One key pre-requisite for bait station design is that baits must be available for long periods (weeks or months) of time. Bait stations were effective in protecting baits from most wet weather. When baits did get wet, then Landcare baits tended to disintegrate into small pieces rapidly, whereas Bait-tek baits remained entire. Therefore, Landcare baits would not be suitable to use when applied in situations exposed to the elements, even though this may increase the number of cats taking baits. Development of a better protective coating, similar to that used on Bait-tek baits, would be useful, if bait attractiveness was not compromised.

Other studies have used many different bait types in trials to poison cats (e.g., "pussoff", "fox-off", Friend and Alger 1993). For two reasons (simplicity of design and ready availability of product) these were not used in this study. We now believe that further trials of other products are warranted, because, used alone, neither of the two baits we used appear to be a sufficiently strong predator control tool. We consider that our study shows that both the bait stations and the baits require further improvement, to increase their attractiveness and overall efficacy at controlling the key predators of black stilts in the Upper Waitaki Basin.

ACKNOWLEDGEMENTS

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APPENDIX 1: LIST OF ALL EVENTS RECORDED ON VIDEO TAPE AT POISON BAIT STATIONS OR ON THE GROUND DURING THREE TRIALS IN 1997 OR 1998.

Event no	Date	Trial no.	Species	Time start	Time finish	Total time	Behaviour	Bait type	Bait age	Station no.	No. of baits eaten
97/001	16-Jun-97	1	Cat	19:12:44	19:13:35	0:00:51	Head in container	Landcare	7	54	0
97/002	19-Jun-97	1	Ferret	0:07:27	0:07:39	0:00:12	Approach station	Landcare	9	16	0
97/003	22-Jun-97	1	Cat	15:00:14	15:23:26	0:23:12	Eat bait	Landcare	13	54	10
97/004	23-Jun-97	1	Ferret	21:36:04	21:36:23	0:00:19	Approach station	Landcare	13	54	0
97/005	26-Jun-97	1	Possum	22:03:25	22:04:27	0:01:02	Approach station	Landcare	16	54	0
97/006a	02-Jul-97	1	Possum	23:21:19	23:43:00	0:21:41	Eat bait	Landcare	22	58	11
97/006b	02-Jul-97	1	Possum	23:22:56	23:43:00	0:20:04	Eat bait	Landcare	22	58	11
97/007	04-Jul-97	1	Cat	16:02:04	16:04:39	0:02:35	Eat bait	Landcare	2	58	1
97/008	04-Jul-97	1	Possum	19:53:41	20:05:42	0:12:01	Eat bait	Landcare	2	58	2
97/009	08-Jul-97	1	Cat	0:51:36	0:52:14	0:00:38	Approach station	Landcare	?	16	0
97/010	09-Jul-97	1	Cat	18:50:40	18:51:05	0:00:25	Approach station	Landcare	?	16	0
97/011	10-Jul-97	1	Possum	23:50:10	23:51:45	0:01:35	Approach station	Landcare	?	54	all baits wet
97/012	11-Jul-97	1	Cat	19:32:41	19:34:11	0:01:30	Approach station	Bait-tek	1	72	0
97/013	19-Jul-97	1	Possum	19:48:36	19:55:42	0:07:06	Eat bait	Bait-tek	11	72	1
97/014	23-Jul-97	1	Possum	23:46:40	23:47:39	0:00:59	Head in container	Bait-tek	16	72	1
97/015	26-Jul-97	1	Cat	18:40:59	18:41:03	0:00:04	Ignore station	Bait-tek	2	25	0
97/016	29-Jul-97	1	Ferret	3:31:36	3:31:52	0:00:16	Approach station	Bait-tek	4	37	0
97/017	29-Jul-97	1	Possum	19:37:55	19:38:12	0:00:17	Head in container	Bait-tek	5	72	0
97/018	01-Aug-97	1	Mouse	3:14:15	3:14:45	0:00:30	Approach station	Landcare	8	24	0
97/019	01-Aug-97	1	Mouse	19:19:58	19:20:03	0:00:05	Ignore station	Landcare	9	24	0
97/020	02-Aug-97	1	Possum	21:38:23	21:46:25	0:08:02	Approach station	Bait-tek	10	57	0
97/021	12-Aug-97	1	Possum	1:30:22	1:31:48	0:01:26	Approach station	Bait-tek	20	57	0
97/022	22-Aug-97	1	Possum	0:19:10	0:19:37	0:00:27	Approach station	Bait-tek	9	13	0
98/001	10-Feb-98	2	Hedgehog	3:22:20	3:22:38	0:00:18	Approach station	Bait-tek	1	3	0
98/002	10-Feb-98	2	Possum	1:50:41	1:53:42	0:03:01	Head in container	Landcare	1	6	0
98/003	11-Feb-98	2	Ferret	23:51:50	23:52:02	0:00:12	Approach station	Bait-tek	1	3	0
98/004a	11-Feb-98	2	Possum	21:42:34	21:52:16	0:09:42	Head in container	Landcare	2	4	0
98/004b	11-Feb-98	2	Possum	3:18:12	3:22:11	0:03:59	Head in container	Landcare	2	4	0
98/005	12-Feb-98	2	Hedgehog	3:03:16	3:03:29	0:00:13	Approach station	Bait-tek	4	3	0
98/006	12-Feb-98	2	Hedgehog	22:30:51	22:37:47	0:06:56	Eat bait	Landcare	4	6	1
98/007	13-Feb-98	2	Cat	0:04:25	0:05:35	0:01:10	Approach station	Bait-tek	5	5	0
98/008	14-Feb-98	2	Cat	10:36:05	10:37:29	0:01:24	Head in container	Landcare	4	2	0
98/009	15-Feb-98	2	Hedgehog	0:26:37	0:27:23	0:00:46	Approach station	Bait-tek	No data	3	0
98/010	14-Feb-98	2	Hedgehog	23:24:13	23:37:11	0:12:58	Eat bait	Landcare	No data	4	8
98/011a	15-Feb-98	2	Hedgehog	21:07:46	21:09:43	0:01:57	Head in container	Bait-tek	No data	5	0
98/011b	15-Feb-98	2	Possum	23:26:00	23:29:08	0:03:08	Head in container	Landcare	7	5	0
98/012	16-Feb-98	2	Possum	21:57:37	21:57:51	0:00:14	Approach station	Landcare	7	5	0
98/013	16-Feb-98	2	Possum	5:54:16	5:56:23	0:02:07	Approach station	Landcare	7	5	0
98/014	16-Feb-98	2	Hedgehog	4:19:44	4:20:26	0:00:42	Approach station	Landcare	8	6	0
98/015	16-Feb-98	2	Hedgehog	21:01:13	21:02:42	0:01:29	Approach station	Bait-tek	7	7	0
98/016	17-Feb-98	2	Hedgehog	22:04:20	22:08:44	0:04:24	Head in container	Bait-tek	8	1	0.5
98/017	17-Feb-98	2	Hedgehog	21:24:58	21:25:44	0:00:46	Approach station	Bait-tek	8	5	0
98/018	18-Feb-98	2	Possum	2:16:44	2:32:12	0:15:28	Eat bait	Landcare	9	4	7
98/019	18-Feb-98	2	Hedgehog	22:46:58	23:00:20	0:13:22	Eat bait	Landcare	9	4	1

Event no	Date	Trial no.	Species	Time start	Time finish	Total time	Behaviour	Bait type	Bait age	Station no.	No. of baits eaten
98/020	18-Feb-98	2	Hedgehog	21:46:07	21:46:35	0:00:28	Approach station	Landcare	8	6	0
98/021	19-Feb-98	2	Cat	18:41:33	18:42:06	0:00:33	Approach station	Landcare	10	4	0
98/022	20-Feb-98	2	Ferret	0:33:06	0:33:17	0:00:11	Approach station	Bait-tek	1	4	0
98/023	23-Feb-98	2	Hedgehog	23:34:39	23:35:11	0:00:32	Approach station	Landcare	1	5	0
98/024	23-Feb-98	2	Hedgehog	19:19:39	19:20:15	0:00:36	Approach station	Landcare	4	5	0
98/025	23-Feb-98	2	Hedgehog	1:47:43	1:48:27	0:00:44	Approach station	Landcare	4	3	0
98/026	23-Feb-98	2	Cat	12:51:27	12:51:44	0:00:17	Head in container	Landcare	4	1	0
98/027	24-Feb-98	2	Hedgehog	23:55:05	23:55:56	0:00:51	Approach station	Landcare	5	7	0
98/028	24-Feb-98	2	Ferret	0:06:24	0:06:42	0:00:18	Approach station	Bait-tek	5	4	0
98/029	24-Feb-98	2	Cat	11:09:41	11:10:00	0:00:19	Approach station	Landcare	5	1	0
98/030	25-Feb-98	2	Hedgehog	21:02:09	21:11:56	0:09:47	Eat bait	Bait-tek	1	2	3
98/031	25-Feb-98	2	Cat	12:51:09	12:52:02	0:00:53	Approach station	Bait-tek	1	4	0
98/033	26-Feb-98	2	Ferret	20:39:38	20:40:29	0:00:51	Approach station	Bait-tek	2	2	0
98/034	27-Feb-98	2	Ferret	21:53:54	21:55:32	0:01:38	Approach station	Bait-tek	3	2	0
98/035	27-Feb-98	2	Ferret	5:12:50	5:13:09	0:00:19	Approach station	Bait-tek	3	4	0
98/036	27-Feb-98	2	Ferret	20:47:57	20:48:27	0:00:30	Head in container	Bait-tek	No data	4	0
98/037	27-Feb-98	2	Hedgehog	22:12:37	22:27:14	0:14:37	Eat bait	Bait-tek	No data	6	3.5
98/038	27-Feb-98	2	Hedgehog	21:43:20	21:46:06	0:02:46	Approach station	Landcare	3	7	0
98/039	28-Feb-98	2	Hedgehog	1:11:10	1:12:28	0:01:18	Approach station	Landcare	3	7	0
98/040	02-Mar-98	2	Cat	10:42:08	10:42:21	0:00:13	Approach station	Bait-tek	4	2	0
98/041	02-Mar-98	2	Ferret	20:44:16	20:44:21	0:00:05	Approach station	Bait-tek	4	4	0
98/042	02-Mar-98	2	Ferret	16:16:48	16:17:11	0:00:23	Approach station	Bait-tek	4	4	0
98/043	03-Mar-98	2	Hedgehog	20:40:03	20:41:15	0:01:12	Approach station	Landcare	1	6	0
98/044	05-Mar-98	2	Hedgehog	21:14:05	21:27:13	0:13:08	Eat bait	Landcare	3	4	10
98/045	05-Mar-98	2	Cat	22:28:49	22:31:20	0:02:31	Ignore station	Bait-tek	3	5	0
98/046	05-Mar-98	2	Hedgehog	1:08:28	1:09:03	0:00:35	Approach station	Bait-tek	3	7	0
98/047	08-Mar-98	2	Possum	23:12:39	23:13:13	0:00:34	Approach station	Bait-tek	6	5	0
98/048	09-Mar-98	2	Possum	20:16:57	20:17:51	0:00:54	Head in container	Landcare	7	4	0
98/049	09-Mar-98	2	Hedgehog	3:37:10	3:38:35	0:01:25	Approach station	Bait-tek	7	7	0
98/050	09-Mar-98	2	Hedgehog	22:49:15	22:49:36	0:00:21	Approach station	Bait-tek	7	7	0
98/051	11-Mar-98	2	Mouse	2:55:48	3:00:21	0:04:33	Approach station	Bait-tek	1	4	0
98/052	10-Mar-98	2	Ferret	23:36:14	23:36:30	0:00:16	Head in container	Landcare	1	7	0
98/053	11-Mar-98	2	Ferret	1:27:10	1:27:22	0:00:12	Head in container	Landcare	1	3	0
98/054	11-Mar-98	2	Hedgehog	0:31:11	0:31:34	0:00:23	Head in container	Bait-tek	1	6	0
98/055	12-Mar-98	2	Hedgehog	2:47:56	2:48:23	0:00:27	Approach station	Landcare	2	5	0
98/056	12-Mar-98	2	Hedgehog	23:15:19	23:15:43	0:00:24	Approach station	Landcare	2	5	0
98/057	15-Mar-98	2	Hedgehog	21:19:09	21:19:39	0:00:30	Approach station	Landcare	6	7	0
98/058	17-Mar-98	2	Hedgehog	3:34:10	3:34:31	0:00:21	Approach station	Landcare	8	5	0
98/059	17-Mar-98	2	Possum	3:33:57	3:34:29	0:00:32	Approach station	Landcare	8	7	0
98/060	18-Mar-98	2	Cat	14:47:15	14:49:37	0:02:22	Head in container	Landcare	9	1	0
98/061	19-Mar-98	2	Possum	21:25:28	21:25:59	0:00:31	Head in container	Bait-tek	9	4	0
98/062	20-Mar-98	2	Hedgehog	2:38:03	2:38:40	0:00:37	Approach station	Bait-tek	1	1	0
98/063	20-Mar-98	2	Possum	20:38:06	20:43:15	0:05:09	Head in container	Bait-tek	1	7	0
98/064	22-Mar-98	2	Hedgehog	23:56:13	23:57:03	0:00:50	Approach station	Bait-tek	3	7	0
98/065	22-Mar-98	2	Possum	0:13:48	0:14:28	0:00:40	Head in container	Landcare	3	4	0
98/066	23-Mar-98	2	Hedgehog	21:10:54	21:11:30	0:00:36	Approach station	Bait-tek	4	7	0
98/067	23-Mar-98	2	Possum	20:19:21	20:20:14	0:00:53	Approach station	Landcare	4	4	0
98/068	23-Mar-98	2	Hedgehog	1:14:14	1:14:41	0:00:27	Head in container	Landcare	4	4	0
98/069	23-Mar-98	2	Hedgehog	4:00:42	4:00:54	0:00:12	Approach station	Bait-tek	4	3	0
98/070	23-Mar-98	2	Cat	0:47:56	0:48:09	0:00:13	Ignore station	Bait-tek	4	1	0
98/071	24-Mar-98	2	Cat	20:11:45	20:12:22	0:00:37	Approach station	Bait-tek	5	7	0
98/072	24-Mar-98	2	Possum	23:14:49	23:18:26	0:03:37	Approach station	Landcare	5	4	0
98/073	26-Mar-98	2	Hedgehog	22:07:26	22:07:43	0:00:17	Approach station	Landcare	7	2	0
98/074	28-Mar-98	2	Cat	8:47:24	8:50:24	0:03:00	Approach station	Bait-tek	8	5	0
98/075	30-Mar-98	2	Possum	2:03:23	2:03:29	0:00:06	Ignore station	Landcare	1	7	0
98/076	01-Apr-98	2	Hedgehog	22:49:21	22:49:36	0:00:15	Approach station	Landcare	2	7	0
98/077	01-Apr-98	2	Hedgehog	23:52:51	23:53:16	0:00:25	Approach station	Landcare	2	5	0
98/078	01-Apr-98	2	Hedgehog	1:12:00	1:12:36	0:00:36	Ignore station	Bait-tek	2	4	0
98/079	02-Apr-98	2	Cat	20:04:51	20:11:09	0:06:18	Eat bait	Bait-tek	3	2	4
98/080	03-Apr-98	2	Hedgehog	3:36:57	3:37:22	0:00:25	Head in container	Bait-tek	3	4	0
98/081	04-Apr-98	2	Cat	10:29:39	10:30:25	0:00:46	Approach station	Bait-tek	5	2	0
98/082	04-Apr-98	2	Possum	23:06:45	23:10:04	0:03:19	Head in container	Bait-tek	5	4	0
98/083	05-Apr-98	2	Hedgehog	5:22:46	5:22:58	0:00:12	Ignore station	Landcare	6	3	0
98/084	05-Apr-98	2	Possum	5:41:29	5:41:44	0:00:15	Head in container	Landcare	6	7	0
98/085	05-Apr-98	2	Possum	21:04:33	21:04:46	0:00:13	Approach station	Landcare	6	7	0
98/086	07-Apr-98	2	Possum	3:47:56	3:48:46	0:00:50	Head in container	Landcare	9	7	0
98/087	08-Apr-98	2	Ferret	2:53:05	3:15:07	0:22:02	Eat bait	Landcare	9	3	10
98/089	28-Apr-98	3	Ferret	13:30:13	13:30:23	0:00:10	Approach station	Station - Bait-tek		10	0
98/090	27-Apr-98	3	Cat	18:08:03	18:15:36	0:07:33	Eat bait	Ground - Bait-tek		1	10.5
98/091	29-Apr-98	3	Hedgehog	20:30:03	20:39:35	0:09:32	Eat bait	Ground - Bait-tek		5	3
98/092	29-Apr-98	3	Hedgehog	23:18:16	23:31:41	0:13:25	Eat bait	Ground - Bait-tek		5	3
98/093	29-Apr-98	3	Cat	13:45:10	13:46:06	0:00:56	Eat bait	Ground - Bait-tek		7	1
98/094	29-Apr-98	3	Hedgehog	22:54:33	23:09:55	0:15:22	Eat bait	Ground - Bait-tek		7	1
98/095	30-Apr-98	3	Hedgehog	1:36:35	1:37:43	0:01:08	Eat bait	Ground - Bait-tek		7	1
98/096	02-May-98	3	Ferret	20:28:40	20:29:51	0:01:11	Eat bait	Station - Bait-tek		4	1
98/097	03-May-98	3	Cat	3:41:52	3:42:11	0:00:19	Ignore station	Station - Bait-tek		4	0

Event no	Date	Trial no.	Species	Time start	Time finish	Total time	Behaviour	Bait type	Bait age	Station no.	No. of baits eaten
98/098	30-Apr-98	3	Cat	15:35:18	15:36:31	0:01:13	Head in container	Station - Bait-tek		4	0
98/099	03-May-98	3	Ferret	19:58:00	19:58:54	0:00:54	Head in container	Station - Bait-tek		4	0
98/100	03-May-98	3	Ferret	22:30:17	22:30:40	0:00:23	Approach station	Station - Bait-tek		4	0
98/101	03-May-98	3	Ferret	23:29:30	23:29:40	0:00:10	Ignore station	Station - Bait-tek		4	0
98/102	03-May-98	3	Ferret	18:38:35	18:38:59	0:00:24	Approach station	Station - Bait-tek		6	0
98/103	01-May-98	3	Mouse	23:21:23	23:22:24	0:01:01	Head in container	Ground - Bait-tek	2	5	0
98/104	01-May-98	3	Cat	18:29:52	18:32:00	0:02:08	Eat bait	Ground - Bait-tek	2	7	0.5
98/105	06-May-98	3	Cat	16:50:30	16:52:14	0:01:44	Approach station	Ground - Bait-tek		1	0
98/106	03-May-98	3	Cat	13:03:50	13:13:16	0:09:26	Eat bait	Ground - Bait-tek		5	3
98/107	04-May-98	3	Hedgehog	21:23:45	21:23:56	0:00:11	Approach station	Ground - Bait-tek		7	0
98/108	04-May-98	3	Possum	22:44:04	22:44:21	0:00:17	Approach station	Station - Bait-tek		6	0
98/109	04-May-98	3	Cat	13:15:22	13:15:26	0:00:04	Ignore station	Ground - Bait-tek		9	0
98/110	06-May-98	3	Mouse	3:25:04	3:26:56	0:01:52	Eat bait	Ground - Bait-tek		5	0
98/111	04-May-98	3	Ferret	1:59:03	1:59:26	0:00:23	Approach station	Ground - Bait-tek		1	0
98/112	06-May-98	3	Cat	2:27:31	2:27:49	0:00:18	Approach station	Station - Bait-tek		4	0
98/113	06-May-98	3	Cat	4:20:38	4:20:43	0:00:05	Ignore station	Station - Bait-tek		4	0
98/114	07-May-98	3	Cat	23:53:57	23:54:25	0:00:28	Approach station	Ground - Bait-tek		9	0
98/115	10-May-98	3	Ferret	5:57:51	5:58:13	0:00:22	Approach station	Ground - Bait-tek		9	0
98/116	09-May-98	3	Possum	3:24:37	3:25:48	0:01:11	Approach station	Ground - Bait-tek		3	0
98/117	10-May-98	3	Cat	0:03:51	0:08:57	0:05:06	Approach station	Ground - Bait-tek		7	0
98/118	08-May-98	3	Hedgehog	23:08:09	23:33:06	0:24:57	Eat bait	Ground - Bait-tek		5	3
98/119	08-May-98	3	Cat	23:17:24	23:26:34	0:09:10	Eat bait	Ground - Bait-tek		5	3
98/120	09-May-98	3	Cat	5:21:49	5:23:33	0:01:44	Eat bait	Station - Bait-tek		?	1
98/121	11-May-98	3	Ferret	22:52:52	22:53:23	0:00:31	Eat bait	Ground - Bait-tek	3	1	0.5
98/122	13-May-98	3	Cat	5:45:55	5:48:45	0:02:50	Eat bait	Ground - Bait-tek	5	1	0.5
98/123	14-May-98	3	Cat	14:40:58	14:41:55	0:00:57	Eat bait	Ground - Bait-tek	6	5	19
98/124	20-May-98	3	Cat	21:29:09	21:40:47	0:11:38	Eat bait	Ground - Bait-tek		1	9.5
98/125	08-May-98	3	Ferret	18:59:06	19:00:52	0:01:46	Head in container	Station - Bait-tek		10	0
98/126	21-May-98	3	Ferret	17:54:37	17:54:54	0:00:17	Approach station	Ground - Bait-tek		7	0
98/127	21-May-98	3	Ferret	22:24:35	22:25:49	0:01:14	Approach station	Ground - Bait-tek		1	0
98/128	12-May-98	3	Possum	6:52:40	6:53:02	0:00:22	Approach station	Station - Bait-tek		8	0
98/129	11-May-98	3	Ferret	0:00:00	0:00:00	0:00:00	Head in container	Station - Bait-tek		8	0
98/130	14-May-98	3	Ferret	4:24:19	4:24:31	0:00:12	Head in container	Ground - Bait-tek		5	0
98/131	14-May-98	3	Cat	13:56:04	13:56:17	0:00:13	Head in container	Station - Bait-tek		8	0
98/132	18-May-98	3	Possum	21:48:00	21:48:43	0:00:43	Head in container	Ground - Bait-tek		1	0
98/133	21-May-98	3	Cat	17:23:57	17:36:08	0:12:11	Eat bait	Station - Bait-tek		10	17.5

Restoration of Motuara Island - Queen Charlotte Sound

Bill Cash and Peter Gaze

Department of Conservation, Private Bag 5, Nelson.

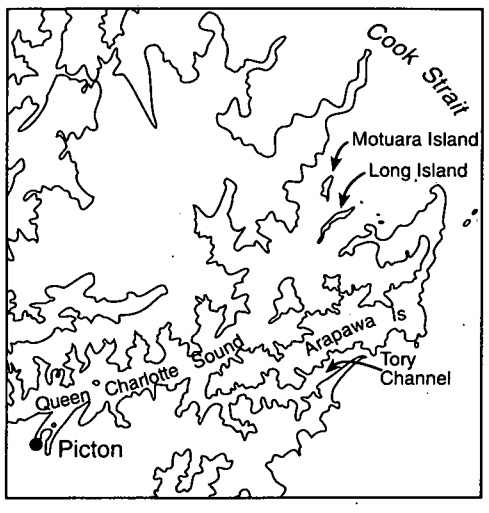
ABSTRACT

Early this century Motuara Island was completely burned and cleared. Since parts of the island were reserved in 1926 and the remainder classified as a scenic and historic reserve in 1976 forest regeneration has been rapid, and in 1991 kiore *Rattus exulans* were eradicated using bait stations and brodifacoum. Technical aspects of this operation are described as is the subsequent natural recovery of the island community along with the introduction and establishment of South Island saddleback *Philesturnus carunculatus carunculatus*, Maud Island frog *Leiopelma pakeka,* and Marlborough green gecko *Naultinus manukanus*. The island is used as a nursery for Okarito brown kiwi *Apteryx australis australis*. There are no restrictions on day visits, which provides benefits in terms of public enjoyment and awareness of conservation values.

BACKGROUND

Motuara is a 59-ha island in the outer Queen Charlotte Sound (figure 1). The island has a long history of Maori occupation, documented in later years by pakeha visitors including Cook who raised the British flag in 1770. Historic sites remain from these times. Early this century the island was used as an experimental goat farm, but despite the history of burning and grazing there has been rapid regeneration over recent decades towards the original forest cover. Today, the predominant cover is tall kanuka *Kunzea ericoides* with a mixed broadleaf understory. In some of the moister eastern parts of the island remannts of kohekohe *Dysoxylum spectabile* forest have persisted. These include some very large trees with elements of titoki *Alectryon excelsus*, tawa *Beilschmiedia tawa*, hinau *Elaeocarpus dentatus*, and the large-leaved milk tree *Streblus banksii*. The coastal fringe is dense and scrubby including akiraho *Olearia paniculata*, mapou *Myrsine australis*, pigeonwood *Hedycarya arborea*, and rangiora *Brachyglottis repanda*.

Figure 1: Location of Motuara Island.



A large colony of fluttering shearwater *Puffinus gavia* is present at the northern end of the island, and blue penguin *Eudyptula minor* and sooty shearwater *Puffinus griseus* breed in smaller numbers throughout. A variety of forest bird species are present, perhaps the most numerous being the bellbird *Anthornis melanura* and the South Island robin *Petroica australis australis*, which are derived from just 5 individuals transferred from the Inner Chetwode in the 1970s.

The Pacific rat (kiore) persisted until the early 1990s.

The site of the old homestead on the western shore is still marked by tall macrocarpa and, while no public camping is allowed, is used as a camping site by conservation staff and research parties. A jetty exists on the western shore near this site, and a track leads to the summit at 130 m where there is a cairn commemorating Cook's visit and a viewing tower. It takes approximately 20 minutes to walk this, the only public track on the island.

THE RAT ERADICATION

While eradication of rodents from an island such as this would be a relatively straight-forward aerial operation these days the technology was not so available in 1990. The eradication was achieved by ground-based application of poison

In preparation for bait distribution a grid of tracks was cut through the island. A main axial track was cut along the 1.4 km main ridge of the island, and at 50 m intervals a side track was cut at right angles from coast to coast. A total of 13 km of tracks was cut taking 3.5 months or 470 staff days. Along these tracks, at 50-m intervals, 280 bait stations were established, each consisting of a 500 mm length of 60 mm or 100 mm diameter yellow novacoil drainpipe with a covered opening at the midpoint for insertion of the baits. These were secured to the ground with loops of fencing wire.

The density of kiore on the island was not measured prior to the operation, however, the island was well known for periodic irruptions, and it was not unusual to see animals during the day. During the preparation for poisoning kiore were abundant enough to be a serious nuisance around the camp.

On 23 August 1991 four pellets of Talon 50WD (15 g wax blocks containing 0.05 g/kg of brodifacoum) were placed in each bait station. This initial laying of the bait took four people all day. A few areas of very steep and dense scrubland were treated by throwing baits into them by hand. On Hippa Island which is a small islet, 20 m to the south of Motuara, bait stations were filled with more baits because regular access was not always possible.

Bait stations on Motuara were checked daily and any baits which had been removed were replaced. After the first night 30% of baits had been removed. The greatest bait take was recorded for the seventh night when 77% of all baits were removed. Note that brodifacoum takes several days to kill a rat and many of these baits would have been taken by rats that had already consumed a fatal dose. On the 14th night only 3% of baits were taken and no bait take was recorded after the 27th night.

On Hippa Island there was no bait take until the fourth night, but then a similar pattern of consumption was observed through until the 23rd night with no bait take thereafter.

During the 20 days of poisoning the occasional dead kiore was seen but more frequently their presence was detected by smell. This smell led to the discovery of one kiore nest with a cache of several talon pellets. On day 12 a few live-capture traps were set and one animal was caught. It appeared healthy but died the following evening with clear symptoms of talon poisoning.

During the 3 weeks of poisoning several dead birds were found: 5 robins, 2 blackbirds, 1 pigeon, and 1 kingfisher. It is reasonable to infer that these birds were poisoned although none was analysed for brodifacoum residue.

POISON FOLLOW-UP

After the first 3 weeks of intensive bait replacement culminating in a nil bait take, field efforts were relaxed and the crew left the island on 19 September. A further three checks were made over the next 2 months. The first of these casual checks was during the week of 8 October 1991 and revealed that all bait had gone from four adjacent bait stations on the western side of the island. These baits were replaced and no new activity was recorded during the next 3 days. These checks noted that while there was no interference from rats, insects were destroying baits. Baits were first protected in tinfoil, which slowed the insect attack somewhat, but robins found these baits appealing and could remove them from the 100-mm bait tunnels. Protecting the baits in self-sealing plastic bags was more successful and found to be just as appealing to rodents.

During the following 2 years all bait stations were kept supplied with protected bait, but checks were as and when convenient. Subsequent checks were made in December 1991, January, May and July 1992 with no rodent interference recorded from any of the baits. During the July visit other attractants were used to help determine if any rodents were still present. One hundred 'chew sticks,' being meat skewers soaked in boiling peanut oil, and 120 pieces of kumara were placed at likely sites around the island. After 10 days these were removed, none having been touched by rodents.

In July 1993 another attempt was made to find sign of rodents, this time using feeding stations with white or dark chocolate. Again, there was no sign. The following month all bait stations were removed, and the island was declared free of rats.

Permanent bait stations were placed at the likely landing sites and baited with sealed and unsealed 50WD and 'Storm' baits. These bait stations are checked whenever the island is visited (never longer than 6 months between visits), and no rodent sign has been detected. Further measures aimed at reducing the risk of re-invasion include bait stations on vessels that regularly visit the island, no mooring to the island or mooring at the jetty overnight and no overnight camping without authority. These measures are consistent with the conservancy's plan to prevent re-invasion of predator-free islands (Gaze 1997).

MANAGEMENT/RESTORATION

The conservancy's island management strategy (Millar and Gaze 1997) acknowledges the high recreation and historic value of the island in addition to its natural values. It further states that this high public use is not entirely consistent with the island's full conservation potential, yet the threat of rodent re-invasion is slight and well managed, and the advocacy value of retaining public access to an island with very visible wildlife is considerable. Management of Motuara over recent years has been successful in promoting these four objectives of restoring biodiversity, maintaining historic values, promoting appropriate recreation, and providing information on conservation.

RESTORING BIODIVERSITY

The return of this island to native cover was phenomenally fast after removal of stock in 1926. Visitors are reminded of this by the occasional encounter with relict fences still in good condition, yet surrounded by tall forest. The density and diversity of species in the understory appears greater since eradication of the rats. Although there has been no scientific study of these vegetation changes those who are familiar with the island have observed that seedling recruitment is much stronger with swards of seedlings now present where the forest floor was previously quite bare. Nikau *Rhopalostylis sapida* seedlings are particularly noticeable.

The island management strategy identified some species which could be transferred to the island to hasten the restoration of biodiversity. These included: Gunther's tuatara *Sphenodon guntheri*, Duvaucel's gecko *Hoplodactyous duvaucelii*, striped gecko *Hoplodactylus stephensi*, Maud Island frog *Leiopelma pakeka*, ngaio weevil *Anagotis stephenensis*, South Island saddleback, little spotted kiwi *Apteryx owenii* and others. The process to date has not followed this strategy closely, but this is not unexpected as our knowledge of the species, their habitat requirements and conservation options has improved.

In 1993, 25 South Island saddleback were transferred to Motuara from Jacky Lee and North Islands within the Titi group adjacent to Stewart Island. Several water catchments were constructed on the island, being a 2 m^2 corrugated iron collection area leading to a small trough fitted with ballcock and perches. These proved popular with saddleback but also tui *Prosthemadera novaeseelandiae*, bellbird *Anthornis melanura* and kereru *Hemiphaga novaeseelandiae*. The saddleback made little, if any, use of the roost boxes and nest boxes provided but nevertheless bred successfully from the first season. Most pairs raised two young each season and another young from a second clutch was not unusual. The 1996/97 season saw island-raised birds breeding for the first time. In autumn 1999 the population had exceeded 100 birds allowing for the further transfer in June of at least 15 to Allports Island closer to Picton.

In 1997 300 of the Maud Island frogs were introduced to suitable habitat on the eastern side of the island. This is believed to be the first inter-island transfer of frogs. Continued monitoring of their survival suggests that they have adapted well, are breeding and dispersing.

Since 1997 the island has acted as a nursery for juvenile Okarito brown kiwi. These birds, which are susceptible to predation in their native habitat, are allowed a year on Motuara in which to grow 'bush wise' in the absence of predators. Each year one cohort is returned to Okarito and another group of adolescents is introduced. So far this operation has seen 10 juvenile kiwi returned to Okarito and another 6 are due to be returned shortly.

The most recent transfer was of 18 green geckos from nearby Arapawa Island in December 1998.

MAINTAINING HISTORIC VALUES

Motuara Island's strategic position at the entrance to Queen Charlotte Sound has been an important factor in its human history. While archaeological evidence of Maori use of Motuara itself does not appear to be extensive, and records are presently limited to several food storage pits, a terrace, and midden, Hippa Island

has been almost totally modified through terracing to form a strongly defensible pa. This pa was occupied at the time of Captain James Cook's visits, 33 houses were noted, and its people were thus amongst the first Maori to have sustained contact with Europeans.

Ship Cove became Cook's primary South Pacific base and during his ships' five visits between 1770 and 1777, Motuara Island was used as an observatory, lookout, signal station, and garden. In January 1770 Cook raised the union flag on top of the island and took possession in the name of George III. During the second voyage in 1773 and 1774 sheep, pigs and goats were released on the island.

Care was taken during track making and placing of bait stations to avoid known archaeological sites and to ensure there was no ground disturbance in their vicinity. This was particularly important in the case of Hippa Island which is almost entirely an archaeological site.

PROMOTING RECREATION AND AWARENESS OF CONSERVATION VALUES

More than any other island in this conservancy, Motuara is providing a popular site for visitors wishing to see wildlife in a predator-free environment. It is consistent with the conservancy's Conservation Management Strategy and Island Management Strategy that the public be encouraged to visit such an island where the risks associated with visitors are outweighed by the benefits of the experience. Past experience shows that visitors to islands can have direct management benefits in terms of their enhanced understanding and advocacy of conservation (Booth 1990). The jetty on the western shore is suitable for off-loading visitors in most weather conditions, and a well-benched track enables relatively easy access to the summit. A 7.5m viewing tower has been reconstructed on the summit and interpretation panels are nearby. Encounters with wildlife along this track have been enhanced through the strategic placement of water troughs and nesting boxes for penguins. Groups such as the Ornithological Society and Forest and Bird organise visits largely because of the saddleback. One commercial charter boat company takes nature tours to the island and many others visit privately.

RESEARCH

The earliest wildlife research that we are aware of on Motuara was by Doug Flack on the robins he transferred from the Chetwodes. Further work on robins was done by Ian McLean from University of Canterbury. Students from both the University of Canterbury and University of Otago have worked on robins, penguins, and saddleback. All of this work has had some logistical support from the department. Parties such as these camped at the site of the old homestead, and a small hut has now been placed on the site to reduce the impact of such intensive use.

CONCLUSION

Kiore were eradicated from this 59-ha island using brodifacoum in bait stations. This hastened restoration of the natural biodivesity of the island and was complemented by a number of species transfers to the island. The primary conservation objectives of safe guarding this process was compatible with conserving historic values, promoting public appreciation of the island, and fostering research. With similar examples like Kapiti and Tiritiri Matangi, it is a pleasing sign that conservation of island communities has progressed to a stage where they can be more freely studied and appreciated by visitors. There are opportunities for further restoration of Motuara and greater involvement and enjoyment of the island by the public.

ACKNOWLEDGEMENTS

The management of Motuara involves a range of staff and expertise too numerous to mention. However the eradication would not have occurred without the specific involvement of Derek Brown, Ian Millar, and Kath Walker whose work is gratefully acknowledged.

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The value of fencing to remove rabbits (*Oryctolagus cuniculus*) from a mainland nature reserve to protect native vegetation and insects

B. McKinlay[1], H. Moller[2], and B. Barron[3]

[1] Department of Conservation, P.O. Box 5244, Dunedin.
[2] Zoology Department, University of Otago, P.O. Box 56, Dunedin.
[3] Department of Conservation, P.O. Box 811, Queenstown.

ABSTRACT

Rabbits were virtually eradicated from the 81-ha Cromwell Chafer Beetle Reserve to protect silver tussocks (*Poa cita*) and native insects. The boundary fence was first rabbit-proofed. A knockdown of 99% of an abundant (34 per hectare) rabbit population was achieved using 1080 poison on carrot bait. The remaining rabbits were removed by trapping, digging, and ferreting. Altogether the fencing and eradication effort in the period 1993-1997 cost $33,631 and is expected to help keep the rabbits at low abundance for at least the next 20-30 years. Fencing helped remove the cyclical nature of rabbit abundance. It has lead to a marked increase in the total vegetation biomass on the reserve, as well as an overall reduction in the ecological management inputs needed on the reserve. Investment in perimeter fencing was quickly repaid and secured ecological protection objectives. More use of fences to exclude predators and browsers from mainland nature reserves should be considered.

INTRODUCTION

Rabbits (*Oryctolagus cuniculus*) can reach enormous abundance in some semi-arid regions of South Island, New Zealand (Gibb &Williams 1994, Moller, et al. 1997). Their browsing can threaten native vegetation and cause erosion, their digging disrupts soil and soil invertebrates, and they attract small mammalian predators. For example, rabbits on the Cromwell Chafer Beetle Reserve (longitude 169° 11'; latitude 45° 11') have markedly reduced the abundance of silver tussock (*Poa cita*) despite intermittent rabbit control and transplanting of tussocks into the reserve from nearby areas drowned by the construction of the Clyde Dam (McKinlay 1997). Silver tussock is a preferred plant on the reserve because the larvae of the endangered Cromwell Chafer (*Prodontria lewisii*) are thought to rely heavily on the roots for food (Watt 1979). Rabbits browse silver tussock and use tussock tillers to line their breeding stops (Gibb & Williams 1990). Their burrowing disturbs soil

profiles and creates areas of clear soil on which weed species such as *Echium vulgare* and *Verbascum thapsus* can flourish. Rabbit numbers on the reserve have been so high that little palatable vegetation was left on the reserve in 1994.

Reductions in rabbit abundance were sought as:

(i) a prerequisite to further transplanting of more tussocks into the reserve;
(ii) to reduce the impact on the soil horizons of the reserve; and
(iii) to maintain what remains of silver tussock as a food plant for the Cromwell chafer beetle.

Rabbits are the main prey of introduced mammalian predators (Alterio & Moller 1997), and predator numbers decline after rabbit control (Norbury & McGlinchy 1996). Accordingly we hoped that the eradication of rabbits from the reserve might also reduce the number of ferrets (*Mustela furo*), feral house cats (*Felis cattus*), and other predators visiting and potentially killing chafer beetles, an undescribed ground weta (*Hemiandrus sp.*), and other insects inhabiting the reserve.

DOC and the Department of Lands and Survey have controlled rabbits by intermittent night shooting and poisoning every 4-5 years since establishing the reserve in 1984. A compensatory settlement from the Central Otago District Council (in exchange for permission to site a refuse disposal facility 1 km from the reserve) enabled DOC to erect a rabbit-proof fence in 1994 and then to attempt complete rabbit eradication within the reserve. Complete eradication of a pest is usually only cost effective if natural or artificial barriers prevent reinvasion of the cleared area.

Fencing coupled with high input control is likely to be attempted more frequently from now on for mainland New Zealand ecological management. Rabbits have been exterminated from at least eight islands around New Zealand (Gibb & Williams 1994), but we know of no other cases where it has been adopted as a strategy to protect mainland protected natural areas. Eradication contrasts with "maintenance control" in which the abundance of the target organism pest is suppressed at below some predetermined "ecological damage threshold" (Moller 1989). This paper describes the methods used for eradication and compares the risks and costs incurred by an eradication strategy compared to sustained control.

PRELIMINARIES

The first essential of any eradication campaign is to ensure that the boundaries of the target site are secure. Current practice for islands is to ensure that there is a sufficient width of water so that animals cannot reinvade. Associated with this is the establishment of passive monitoring tools to detect any reinvasion (McKinlay 1997). A fence secures boundaries for a mainland protected area but otherwise the same philosophy is applied. At Cromwell an earlier rabbit-proof fence was ineffective, mainly because the rabbit netting was laid along the ground rather than buried. It was therefore replaced completely. The new fence incorporated rabbit netting (40 mm diameter) and was buried to a depth of 0.6 m (McKinlay 1994). The fence cost $2.41 a metre to erect along a total boundary of 4.2 km. The total cost of the fence was $10, 101 including GST (all costs are reported as NZ dollars at 1994 value).

NIGHT SHOOTING

As part of the continuing rabbit control before the fence reconstruction, 2 nights and 1 day of shooting were done per 6-week period from July 1992 to April 1994. Rabbits were shot by .22 magnum rifle and 12-ga. shotgun from the back of a utility vehicle while using a 12 V powered spotlight. This required three people (driver, spotlight operator, and shooter) for about 2 hours work (and an additional 2 hours travel time). A standard beat along 10.62 km of vehicle tracks passing back and forth over the reserve and around its edge was covered during each operation. The number of rabbits shot per km and per hour did not change over the time of this operation (Spearmans Rho= 0.373, N=16, p=0.154). This implies that shooting at this frequency contained further population growth. The total cost of this maintenance operation was $5257 comprising labour (at $17 per hour; 82%), travel (at $0.40 per km; 16%), and ammunition (at $0.20 per round; 1.2%).

Shooting was discontinued in April 1994 to leave at least 3 months of no disturbance prior to the poisoning operation. Shooting or other disturbance is considered to make rabbits less likely to take poison baits.

ESTABLISHING A RABBIT MONITORING METHOD

The next priority was to devise a rapid and effective method of monitoring rabbit abundance to measure the progress of and to guide the intensity of the eradication efforts. An observer walked daytime transects to count the number of rabbits seen 37 times on 15 different days between 29 June 1994 and 19 July 1994 (Moller et al. 1996). Any rabbits first spotted behind the perpendicular line passing through the counter's position were excluded, unless they subsequently ran forward of the counter.

Distribution of rabbits is extremely patchy (Moller et al. 1996, Fletcher et al. 1999) so the fixed path is essential to get a reliable measure of the reducing rabbit abundance as eradication proceeds. Recording separate counts between each 100-m peg is useful to target pockets of live rabbits remaining as the eradication attempt proceeds. The walking pace of our observer turned out to be about 1 m/sec. This may vary according to terrain and vegetation cover. (The chafer beetle reserve is nearly flat and at this time was devoid of high vegetation.)

Several practice runs are advised before regular monitoring begins to factor out the learning phase of the counter. Our counter recognised that she soon learned where most of the rabbits were active, and consequently may have gradually changed her searching behaviour to detect more of them as the study progressed. The influence of climatic and other variables on the counts can later be "filtered out" by regression analysis to give the most reliable index of rabbit numbers. In our campaign only frost and/or cloud cover was important. There was little rain or wind during our study so these variables might affect other eradication attempts (Moller et al. 1996).

Analysis of our results showed that by far the least variable counts, and therefore the best times to do counts, were during the mid afternoon and dusk (Moller et al. 1996). In our study there was a statistically significant reduction in the rabbit count if a count had been taken about 2.25 hours earlier. Clearly some rabbits do not re-emerge once they have been flushed down burrows by the counter. However, if time is short two successive transect counts in the afternoon will provide useful added statistical depth to that obtained from a single count.

Rabbit counts are frustratingly variable. Our measures indicate that about 20 dusk counts are needed to estimate the mean with 80% precision; and that 80-90 are needed to achieve 90% precision (Moller et al. 1996). Variability in counts will change between sites and seasons, but we suggest that managers budget to count 20 times at each pivotal time of eradication programmes. Reliance on fewer counts may seriously mislead decision making on whether to scale eradication or control efforts up or down.

The transect counts indirectly assisted the eradication attempt by emphasising the increased above-ground activity in afternoons and at dusk. The last few rabbits were more likely to be spotted by concentrating searches in the late afternoon.

From our experience at the Cromwell Chafer Reserve we recommend the following methods to standardise the count and to measure the influences of weather and disturbance on the abundance index:

(i) Peg out 100 m segments of a transect traversing the whole study area;

(ii) Walk the entire transect slowly and steadily, scanning from side to side at the most comfortable speed to ensure that all rabbits being flushed ahead are counted;

(iii) Whenever possible use a single observer for all the counts to avoid variation from differences in eyesight, speed of walking, and scanning etc;

(iv) All rabbits seen running or standing forward of a perpendicular line to the transect (passing through the observer's position) are counted. Care needs to be taken to avoid double counting rabbits;

(v) Counts should be completed between afternoon and dusk. Do not start before 14:00 hours (NZST) and start as late as possible in the afternoon so that at the end of the count there is still sufficient light to detect a rabbit at 100 m distance;

(vi) Weather and disturbance should be scored during each count i.e.:
   (a) Rainfall - dry/slight/heavy;
   (b) Wind - using the Beaufort wind force scale, (or a hand-held electronic wind anemometer can be used if available);
   (c) Cloud cover (in eighths);
   (d) The presence of pre-feed baits (for subsequent poisoning) should be noted, because earlier research has shown that it sometimes alters rabbit activity patterns;
   (e) Any disturbance (usually people with their dogs in our case).

(vii) The counts are analysed by pooling all 100-m segments for each count and taking a mean and standard error of the total in each separate pass over the entire transect.

RABBIT POISONING

The next step was to rapidly reduce rabbit abundance using poison. The Otago Regional Council spread 8.64 kg/ha of carrot pieces by helicopter in the first week of August 1995. 1080 was applied to carrot pieces at a rate of 0.02% (w/w). A non-toxic prefeed was applied 7 days before the toxic application. Aerial application increased the costs but removed the potential impact of vehicles compacting soils on the reserve. Carrot and 1080 were chosen as the preferred lure and toxin respectively over pindone and grain because they were likely to give a better kill. We poisoned well before spring insect emergence started. Also, rain dilutes the toxin and 1080 breaks down in the soil, but we also removed left over baits to

further reduce risk of 1080 poisoning of insects. The poisoning operation cost $3770 ($46.5 per ha).

Twenty-one counts along the same transect between 12-19 August 1994 (2 weeks after the poisoning) gave an average of 0.428 (95% ci=0.010) rabbits. The pre-poison average count was 44.972 (95% ci=0.243). Assuming a linear relationship between rabbit counts and absolute rabbit abundance, this equates to a 99.03% to 99.10% reduction in rabbits by poisoning. There is some evidence of saturation of rabbit counts at high densities (Fletcher et al. 1999) so the real reduction in rabbit numbers may have been even greater than 99%.

Highly effective poisoning gave this eradication attempt the best of possible starts. It probably was the single most important factor in the overall success of the campaign, yet the poisoning operation took only 10% of the overall programme cost (including the cost of the fence).

In the second week of August, the Highcliff Conservation Corp members scooped up uneaten baits and all the dead rabbit carcasses from the surface of the reserve. Repeated frosts and thaws turned uncollected baits to mush, so that by 20 August 1994 there was no sign of baits on the reserve at all.

FOLLOW-UP CONTROL AFTER POISONING

Our intention was to destroy all remaining escape cover for rabbits and to deny them shelter. One person was employed full time on follow-up work from 22 August until 10 November 1994 (12 weeks - 3840 hours). This contract worker first filled in all rabbit burrows, whether being actively used or not. Then he re-inspected all filled-in areas to see if burrow entrances had been reopened. A leghold trap was set at all reopened burrow entrances, or the entire burrow was dug up to catch and kill the rabbits within.

Trapping was undertaken using unpadded Victor leg hold traps. A total of 4068 corrected trap nights were completed in the 12-week period (See Cunningham & Moors 1996 for a definition of a 'corrected trap night'). Overall 0.64 rabbits were caught per 100 corrected trap nights. Altogether 26 rabbits, one cat, and one stoat (*M. erminea*) were trapped, and 2 rabbits were dug up and killed.

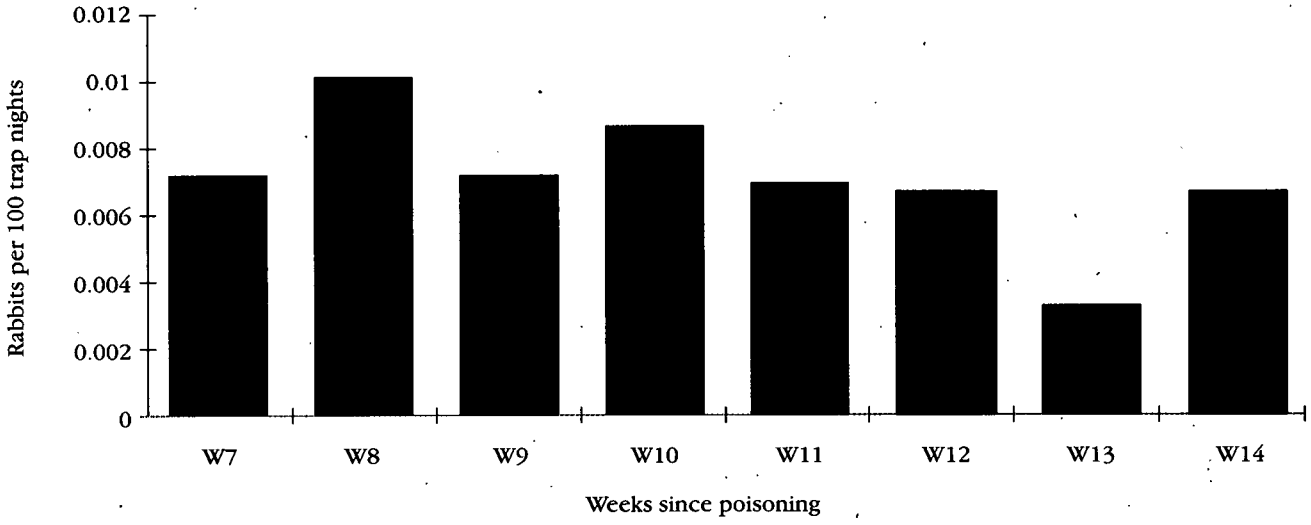
There was a significant decline in catch rate over the 8-week period that trapping was undertaken (Spearmans Rho= -0.762, N=8, p=0.044) (Figure 1). A steeper decline would have occurred had we not targeted trap placement so tightly on those burrows where continued rabbit activity had been noted.

Near the end of the contract for this work it became clear that rabbits were being trapped that had invaded the reserve. We eventually found a warren outside the boundary fence that had a long tunnel under the track and fence. This shows the value of monitoring progress while mopping up the last few rabbits. We went looking for the source of the leakage because rabbit sign indicated a potential problem.

The contract for the follow up work cost $5000 (or $462 per hectare) and killed 28 rabbits ($178 per rabbit). The 28 survivors of the poisoning represented 1% of the original rabbits. Therefore about 2800 rabbits were killed at a cost of $3770 equivalent to only $1.34 per rabbit. Per capita costs of initial control is therefore 132 times less costly than the final campaign to kill the last few rabbits.

At the end of the contract there were no usable burrows left on the reserve. The removal of rabbits triggered an easily observable increase in biomass even before

FIGURE 1: RABBITS CAUGHT PER 100 CORRECTED TRAP NIGHTS PER WEEK AT THE CROMWELL CHAFER BEETLE NATURE RESERVE; SPRING 1994.



the next growing season was half-way through. Assuming a 99% success for the poison operation and that all 28 of the rabbits caught after poisoning were resident (i.e. that the population was "closed" since poisoning) gives a rabbit density of 34 rabbits per hectare before the poison. This is higher than the average of 19 rabbits per hectare measured in the MacKenzie Basin after an unusually cold winter had reduced their high numbers (Moller et al. 1997). This high abundance at the Cromwell Reserve had occurred despite expensive and sustained control 10 years before this eradication attempt.

ONGOING PROGRAMME

Since spring 1994 management of rabbits on the reserve has involved:

- maintenance of the fence,
- continued walking of the reserve to destroy any new burrows (this forms part of a monthly work programme in the area) and killing rabbits by digging up any burrows,
- use of larvacide gas (MAF 1991) in burrows in the area immediately around the reserve,
- use of a ferret to catch rabbits down burrows,
- continued liaison with adjoining landowners to ensure that they maintain control on rabbits.

A large number of scratchings and starting burrow holes indicated intense challenge of the fence by rabbits living around the reserve. The relatively large amount of feed inside compared to outside the reserve probably creates this pressure. In the period from summer 1994/95 to winter 1997 a further 21 rabbits have been removed from the reserve by DOC staff. An independent ferreter caught an unknown number of other rabbits. Ten members of the Highcliff Conservation Corps systematically traversed the reserve in August 1997 and killed 2 rabbits.

The maintenance of the fence is a key priority in protecting the investment already made. There has been one hole made in it by vehicles. Immediate follow-up work (using walk over methods and ongoing burrow destruction) after repair of such holes has not revealed detectable increases in rabbit numbers.

DISCUSSION: COSTS AND BENEFITS OF ATTEMPTING ERADICATION

Did we succeed in eradicating rabbits?

The ongoing removal of a small number of rabbits 3 years after our intensive eradication attempt probably indicates that total removal of the original rabbits failed. However, the infrequent holes or digging new burrows under the fence may have restarted populations in the reserve from immigrants. Continual finding of more rabbits surprised us because their presence was not obvious during the three years after our eradication attempt. This emphasises the need for extreme vigilance to detect low-density rabbit populations. Perhaps the combination of our having destroyed burrows and the ongoing maintenance control was sufficient to prevent the resurgence of rabbits that would normally have been very evident 3 years after poisoning in this semi-arid habitat (Gibb & Williams 1990).

The value of the rabbit fence

Our fence, even if not totally rabbit-proof, was probably the key determinant of slow rabbit resurgence. It will have greatly slowed if not totally eliminated immigration into the reserve from surrounding land. Farmers use rabbit-proof fences to reduce the movement of rabbits between blocks (MAF 1991). At Cromwell we were determined to have a higher standard of prevention because of the ecological damage that would occur well before rabbits had built up to high enough numbers to justify a re-poison. It was important to have confidence that we could manage rabbits on the reserve without rabbits in surrounding non-poisoned land compromising the ecological protection we sought. Securing the fence allowed DOC to work independently of the neighbours.

Cost of fencing and eradication

Clearly the key part of DOC's investment is in the maintenance of the fence (Table 1). Failure to quickly repair even a small gap could rapidly erode the benefits gained. Fence maintenance consists of inspections by one person, which take about 2 hours per 3 months. This is a total of $136 per annum. Any gaps are closed up with rabbit netting which is held in stock. In the period 1994-1997 approximately 3 m of rabbit netting has been used. A roll of rabbit netting costs $110 and at this rate one roll can be expected to last 30 years. With care and maintenance a rabbit fence in Central Otago can be expected to last 20-30 years, so the annual cost of maintenance is about $140 (or $8.35 per km). Assuming a 25-year life for the fence, the cost of its establishment and maintenance will have been $544 per year or $6.7 per hectare per year. A 4-year poisoning cycle and maintenance control by night-shooting would have cost $3776 per annum. The capital investment in the fence would therefore have been recouped if just 1-2 less poisonings had been completed over the 25 years. Lack of resurgence by 1997 makes us confident that at least one cycle of poisoning had already been saved in the first 4 years.

As with most eradication attempts (Parkes 1993) the effort to kill the last few target individuals rises exponentially as the end of the removal programme nears. This added effort and expenditure is essential if the crucial goal of killing the last animal is to be achieved. If there is a significant risk of not killing this last individual or of reinvasion occurring, the eradication strategy is unlikely to be as cost effective

TABLE 1: SUMMARY OF DOLLAR COSTS FOR ERADICATING RABBITS AT THE CROMWELL CHAFER BEETLE RESERVE, 1993-1997, AND LIKELY COSTS OF ONGOING CONTROL IN ABSENCE OF THE RABBIT FENCE.

ACTIVITY	ERADICATION ATTEMPT		PER ANNUM COST OF FENCING AND ERADICATION DISCOUNTED OVER 25 YEARS	PER ANNUM COST OF 4 YEAR POISONING AND NIGHT SHOOTING WITHOUT FENCING OR ERADICATION OVER 25 YEARS
	Cost		Cost	
Fence	10101	28%	404	
Nightshooting	5257	14%		2816
Poison	3770	10%		960
Follow-up	5000	14%	544	
Ongoing programme 1994-1997	11500	32%		
TOTAL	35628		948	3776

as a sustained control attempt where pushing on to get the last few individuals at relatively high cost is avoided. In our case, we let a fixed contract to exert maximum pressure on the remaining rabbits in the 15 weeks following poisoning. Pushing on to remove every last rabbit would have been extraordinarily expensive and may not have been possible, let alone cost effective. Even occasional breaches of the fence in the next 3 years would have undone the value of added expenditure to persue the last resident rabbit.

Ecological benefits

Tussocks that were previously moribund from over browsing have sprouted and in some cases been prolific seeders. Rabbits are no longer part of the ecological processes on the reserve. The standard 3-5 year re-poison cycle prevents the vegetative recovery that has been observed occurring. Additionally work programmes (organising the poison, obtaining consents) would have to be increased and decreased as the cycle ensued. The investment made with this programme has meant that a low-level work programme is consistently maintained.

Future management of the reserve

Complete eradication of rabbits is not without its risks of unwanted side effects. For example, rabbit eradication from Motunau Island proved detrimental to conservation there because woody weeds proliferated in the absence of some rabbit browsing (Taylor 1968). Massive reduction of rabbits in the United Kingdom following the arrival of myxomatosis caused major changes in vegetation, and this lead to the extinction of a butterfly (Sumption & Flowerdew 1985). Unwanted ecological effects could follow sustained rabbit control (Moller 1989, Moller & Raffaelli 1998). At Cromwell the removal of rabbits has lead to a dramatic increase in vegetation (Ferreira & McKinlay in press a). A key feature of this increase mainly by introduced adventive annual species has been the removal of bare ground. We

are still not certain whether this is beneficial for the chafer beetle. Analysis of trapping data shows no obvious decline (Ferreira & McKinlay in press b), but the rabbits have not been severely reduced for long enough to measure this risk. Adult beetles have been observed feeding on exotic plant leaves and may even benefit from an increase in plant biomass. We do not know whether a similar situation applies for the larval stages of the beetle.

However trapping records have shown a decline in the ground weta (*Hemiandrus sp.*) which is found on the reserve (unpublished data). It may be that those management practices that favour one herbivorous insect will disadvantage others. Accordingly there may be both an optimum minimum and a maximum level of browse to enhance the conservation values of the Cromwell Chafer Beetle Reserve. Browsing is a form of ecological disturbance, and the intermediate disturbance hypothesis states that biodiversity will be greatest at intermediate levels of disturbance (Collins & Glenn 1997).

Research to identify a minimum level of beneficial browse would be expensive, time consuming, and complex. We have opted instead to dedicate the available research funds to perfect insect monitoring techniques and to better elucidate their ecological requirements. Having virtually eliminated the rabbits, we will now monitor the vegetation and insect responses. In the worst case scenario, downward trends in weta or chafer abundance might force re-introduction of rabbits or another browser to the reserve. The boundary rabbit-proof fence would still then be an asset to management by preventing re-invasion from surrounding rabbit-prone land following our renewed ongoing control campaign inside the fence. It will be much easier and cheaper to keep the rabbits between the prescribed limits because the partial barrier to immigration remains intact.

The arrival of Rabbit Haemorrhagic Disease (RHD) in Central Otago in spring 1998 has dramatically reduced rabbits at Cromwell.

Not only are rabbits no longer present inside the reserve but they are absent outside it as well. It will take time before the effects of RHD in terms of new numbers of rabbits present in the Cromwell area are noted and understood.

CONCLUSION

Long-term rabbit control at the Cromwell Chafer Beetle Reserve has been made cheaper and more convenient because of the fencing we established. It has led to better protection of endemic biota. We urge mainland conservation managers to consider more use of fencing to allow complete eradication or "management for zero density" of mammalian pests from more mainland nature reserves in future.

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Monitoring with callipers: the potential value of fluctuating asymmetry measurement in conservation monitoring, management and research

Murray Williams

Science & Research Unit, STIS, Wellington

ABSTRACT

Measuring the extent of asymmetry between left and right characters of a bilateral trait (fluctuating asymmetry) in plants and animals can provide a simple method of monitoring genetic and environmental stress affecting populations, ecosystems and individuals. Field methods are uncomplicated. Essential equipment is a set of callipers, and analytical techniques are well prescribed and documented. A burgeoning scientific literature, major texts, and web sites underpin and support the application of fluctuating asymmetry analyses in conservation and environmental monitoring, management, and research.

WHAT'S THIS ALL ABOUT?

Frogs are declining world-wide and you wish to monitor some native frog populations for early signs of trouble. There are a number of small remnant populations of a rare skink and you seek to prioritise these for management attention. Conservation of black robin could be advanced by establishing a third population on Pitt Island, but how suitable is the remnant bush habitat there? A nursery has numerous plants of a threatened species but you wish to plant out only those likely to have the best growth performance. You are at a yearling sale, you have a choice of four as your potential super money-winner; which one to buy? Four real conservation issues and one life-and-wealth question. All are potentially resolvable using the very same technique. All can be addressed with nothing more sophisticated than a set of callipers and an EXCEL spreadsheet. All involve the practical step of measuring the left and right elements of one or more bilaterally symmetrical characters - fore and hind limbs, wing and/or tail feathers, leaf or flower shape, facial features - then computing and comparing the extent of the left-right differences (i.e., the asymmetry) within and between populations, or in the case of the horses, between individuals.

And the very same simple approach and techniques may allow you to address such diverse environmental issues as:

- monitoring water quality in streams and rivers
- detecting pollutant impacts on land and in water
- monitoring disease status and susceptibility
- determining relative habitat quality
- assessing plant or animal quality, especially of those artificially raised
- determining best source populations for translocation
- monitoring environmental manipulations (e.g. predator, pest, weed removal)
- assessing population "health" or fitness

and the approach may apply equally well to plants and animals, at population and ecosystem levels, and (with some caution) to a comparison of individuals.

A universal method ? Probably not! But most certainly it is a method worthy of immediate application to many conservation issues and of careful evaluation for addressing others. The concepts of developmental stability and fluctuating asymmetry which underlie this potential monitoring and management technique (and which I will explain later) are supported by a burgeoning scientific literature, modern texts, established statistical and analytical methodologies, and an expanding number of web sites. Fluctuating asymmetry and its application to plant, animal, and environmental management and research is a 'hot' (and occasionally controversial) subject currently. It is also one we can apply now, and by so doing, collectively evaluate its applicability in the New Zealand context.

But first, let me take one step back to explain the context of this article and its subject material.

MONITORING FOR CONSERVATION PURPOSES

"One of the most important, and often most difficult, tasks associated with biological conservation is the identification of populations subject to 'stress' before that stress has a detrimental effect. An early warning system capable of identifying vulnerable populations does not exist among current available biological and environmental monitoring techniques. Changes in population or life history parameters such as survival, fecundity, reproductive success, community structure, species diversity, and relative abundance or density are most commonly assessed within conservation biology monitoring programmes. The major difficulty with this approach is that by the time the species responds negatively and in a detectable way to changing environmental or genetic conditions affecting the populations monitored it may be too late for remedial action. There is a pressing need for the development and application of a biological monitoring system that measures stress-mediated effects *before* changes in fitness (i.e. population 'health') itself are evident, an indicator system that *predicts* subsequent changes in life history parameters (slightly paraphrased from Clarke 1995).

What Clarke is alluding to is the age-old problem of being wise after the event. Seemingly out of the blue a plant or animal population declines, and it is in decline (sometimes in very steep decline) before we actually notice it, and certainly before we respond to it. How nice to have a monitoring technique that might allow *prediction* of an impending decline! Clarke also makes the point, well known to all of us, that most monitoring programmes collect data over several years and we determine the state of whatever we are monitoring by appraising the trend across years. Any change is well underway before we detect and document it.

Furthermore, the data we gather are often repetitive, hard to get, demanding of considerable time, effort and money, and seldom obtained on a scale that is statistically adequate. Surely there is a better way?

Clarke (1995) building upon the idea expressed earlier by Leary & Allendorf (1989) and endorsed by many authors subsequently (see information and reference sections), suggests there is a better way. It lies in measuring an organism's developmental stability. Yikes!

CONCEPT OF DEVELOPMENTAL STABILITY

"You see one (blue) duck, you see 'em all" - so the saying goes. There may be subtle differences between some ducks' but by and large they do all look pretty similar. The package of genetic material that develops a blue duck can generally withstand a range of environmental and genetic disturbances during development to produce a pre-determined form - the phenotype that we all recognise as a "blue duck".

Developmental stability refers to the suite of genetically-controlled processes which work to reduce phenotype variation resulting from developmental accidents and deliver our standard "blue duck".

Under optimal conditions, the development of our blue duck proceeds along a genetically determined pathway. Any hiccup in cell division or cell chemistry that may randomly arise is countered by the developmental stability processes and the pre-determined phenotype arises. But under stressful conditions, and that stress can arise from anything like temperature, nutrition, density, pollutants etc., the efficiency of the stability processes is reduced and this may result in a phenotype just a little different from 'normal', e.g. smaller size, growth deformity. In the literature these may be called 'aberrant' or 'abnormal' phenotypes, or (my favourite) a 'phenodeviant'.

Under any given set of environmental conditions not all phenotypes will be identical. The developmental stability processes of some will buffer them against prevailing conditions better than others. Individuals better able to buffer development are considered at a selective advantage, i.e. they are the fitter individuals whose probabilities of living longer and leaving more descendants are all that much higher. Populations containing higher proportions of these fitter individuals are predicted to be more persistent under those conditions.

Thus, the developmental stability processes, in determining the fitness of the individual, are influencing the fitness of the population to which the individual belongs. If changes in developmental stability of individuals can be measured then collectively they may predict ensuing changes in population fitness before any detectable changes occur in the more direct and customary measures such as survival, fecundity, or longevity. So how can we measure developmental stability?

MEASURING DEVELOPMENTAL STABILITY

A range of methods have been used to measure the expression of developmental stability (see Møller & Swaddle 1997: Table 1.1). Many have proved restricted in their application and suspect in interpretation. Those now most commonly used are:

- Frequency of phenodeviants within and between populations, e.g. number of fish with jaw deformities in lakes of differing pollutant levels. This method does suffer from arbitrary interpretations (e.g., how much deformity represents a real deformity compared to random variation within the population?) and from small sample sizes since abnormalities are generally quite rare.
- Frequency of asymmetric characters. This method has been used when the characters being assessed differ in a qualitative way, e.g. intensity of colour. Alternatively, when a large number of traits are under investigation, e.g. multiple skull bone characters, and among-individual differences are being examined, it may suffice to record them as 'symmetric' and 'asymmetric' and calculate frequencies.
- Fluctuating asymmetry. Development of the two sides of a bilaterally symmetrical organism (and that's most life forms) are under identical genetic controls such that non-directional differences in expression of left and right must be environmentally induced and reflect the imprecision of the developmental stability processes. The differences between left and right expressions of a single trait, e.g. their length is a measure of developmental stability. This is called fluctuating asymmetry because the differences between sides will vary - in some individuals left > right, whereas in others it is the reverse. Across a population, the average expression of the difference between the two sides is zero. If one side is always larger than the other, then you are dealing with 'directional' symmetry (like the enlarged claw of the male fiddler crab), and this is not a measure of developmental stability.

Fluctuating asymmetry is the measure that has the greatest following. So how can this simple difference between left and right sides of 'things' be used in conservation management and research practice? Here are a few recent examples.

FLUCTUATING ASYMMETRY APPLIED

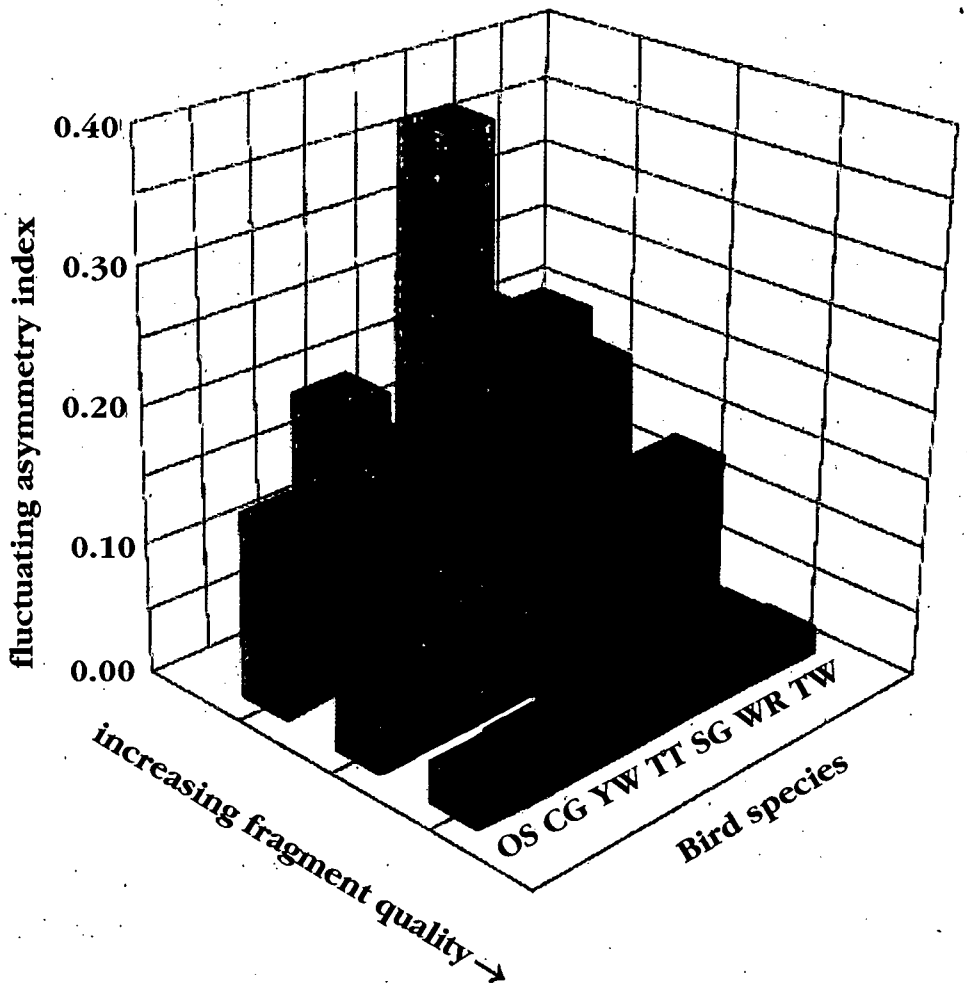
1. Forest fragments as bird habitat

The quality of three tropical forest remnants in Kenya, of differing sizes, altitude and disturbance histories, was appraised using 10 different parameters (stem density, species diversity, canopy cover etc.) and ranked relative to each other. Samples of each of seven bird species resident in the low-middle canopy in all three forests were caught, and the left and right tarsus of each measured. The results are summarised in Figure 1. For each species the extent of tarsus asymmetry was different between forests, being greater in the poorest quality forest and least in the highest quality forest. Overall, individuals were four to seven-fold more asymmetric in tarsus length in the poorest forest compared to the best (Lens et al. 1999). Conclusion: asymmetry measurements offer a direct and bird-centred method of evaluating relative habitat quality.

2. Leaf symmetry and disease in elm trees

Twenty apical leaves were collected from branches at the same height and side of each of 78 same-aged elm trees planted as a hedgerow. Leaf symmetry was assessed by measuring the left and right 'mid rib to margin' distances at each leaf's widest point and measuring distances between side veins on either side of the leaf rib nearest to the leaf's widest point. Asymmetry of leaf shape was monitored annually

FIGURE 1. LEVELS OF FLUCTUATING ASYMMETRY IN TARSUS LENGTHS OF SEVEN SPECIES OF FOREST BIRDS IN RELATION TO QUALITY OF THEIR FOREST FRAGMENT HABITAT. IN ALL SEVEN SPECIES THE EXTENT OF ASYMMETRY WAS GREATEST IN THE POOREST QUALITY FRAGMENT AND LEAST IN THE HIGHEST QUALITY FRAGMENT. (FROM LENS ET AL., 1999)

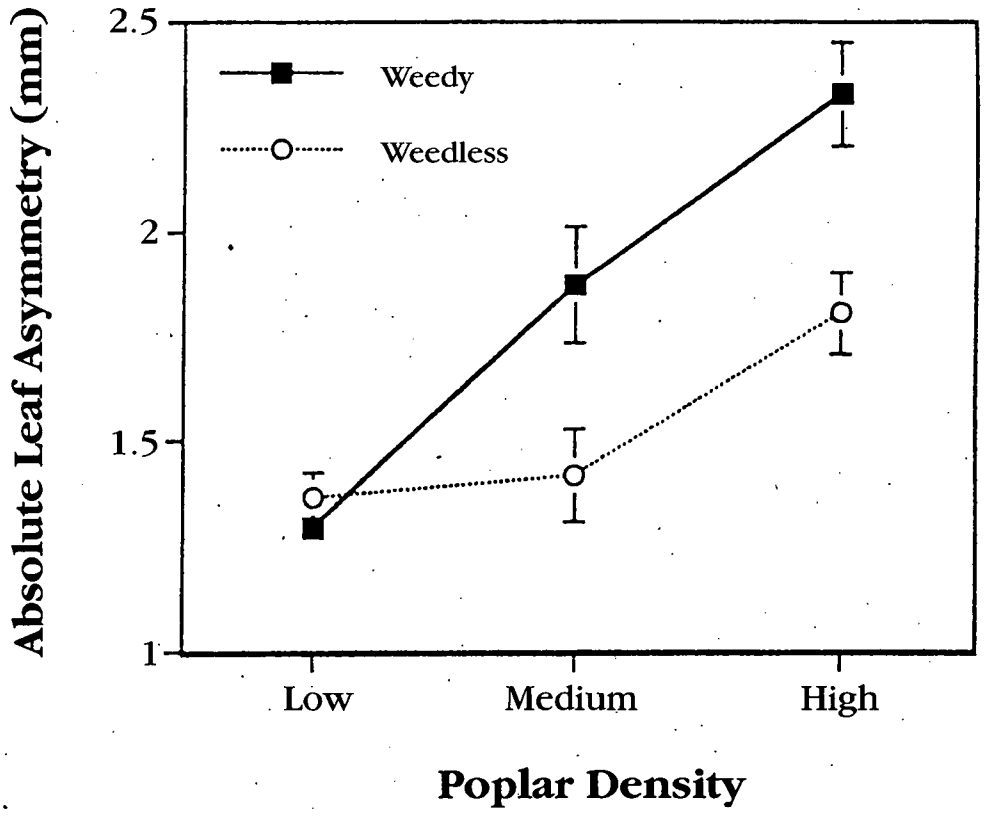


over 5 years during which time some of the trees contracted Dutch elm disease. Leaf width and inter-vein asymmetries of diseased trees were significantly greater than in healthy trees, and the extent of asymmetries was greater in trees that had been infected for longer. Healthy trees that later became diseased had larger leaf asymmetries than immediate neighbouring trees that did not (Møller 1999). Conclusion: asymmetry measurements indicated disease susceptibility and provided a measure of relative progress of the disease.

3. Competitive interactions between plants

As an experiment, even-aged poplars of the same clone were planted in plots varying in density. Some plots were kept free of surface weeds, others were not. Leaf symmetry was measured using mid-rib to margin distances at each leaf's widest point. Leaf asymmetry was greatest in plots of highest stem density (Figure 2), and its extent was more extreme in plots with surface weeds (Rettig et al. 1997). Conclusion: leaf asymmetry can provide an indication of competitive stress in plants.

FIGURE 2. EXTENT OF LEAF ASYMMETRY OF POPLAR TREES GROWN AT DIFFERING DENSITIES AND WITH/WITHOUT THE PRESENCE OF SURFACE WEEDS. (FROM RETTIG ET AL., 1997)



4. Ranking of lizard populations

Genetic diversities of three mainland and six island populations of a rare Australian lizard were examined using electrophoresis of blood proteins. Heterozygosity levels were high in all populations (10.5 - 16.8%) and no population was significantly different from another, although all island populations had slightly lower allelic diversity than mainland ones. However, asymmetry of three morphological characters was significantly higher in four island populations than in all others (Sarre et al. 1994). Conclusion: asymmetry data indicated four populations may be under greater environmental stress than the others and, thus, priority targets for management and/or research.

5. Swallow tails

In a series of experiments, the long outer tail feathers were altered to test how resulting feather asymmetry influenced various aspects of the bird's ecology. Tail asymmetry affected aerial performance and induced compensatory changes in tail muscle size and was significantly higher amongst birds taken as prey by hawks than in a random sample of live swallows. Length and symmetry of a male's tail feathers influenced the probability of and the speed with which it found a mate, its timing of reproduction and the number of offspring raised per season (summary in Møller & Swaddle 1997). Conclusion: asymmetry of a sexually and mechanically important trait, like a tail, can affect an individual's survival and reproductive legacy,i.e. provide a measure of individual fitness.

6. Correlates of contamination

Levels of asymmetry of various morphological characters in plants and animals have been significantly correlated with contaminant levels in many studies, e.g. pectoral fins in fish with DDT levels, shrew skull features with heavy metals, seal skull measurements with oceanic pollutants, bristle characters in bush flies and fruit flies with pesticide residues, skeletal features in shags with PCBs, various fish species with water acidification, swallow tails with radioactivity levels, birch tree leaves with air pollution, algae with water quality, and new-born children with their mother's alcohol consumption (references in Møller & Swaddle 1997). Conclusion: character asymmetry can indicate the presence and intensity of environmental contamination.

These examples illustrate just part of the diversity of research and management questions for which fluctuating asymmetry measurement has provided appropriate answers. Particularly appropriate to New Zealand conservation management would be comparisons over time of the sort typical of many long-term monitoring programmes or before-after comparisons associated with some management manipulation.

HOW TO USE

The seduction of fluctuating asymmetry as a monitoring or research tool is its practical simplicity. The essential data are collected by measuring the left and right expressions of a bilateral trait. There are, however, some important considerations before venturing into the field.

What question to ask

Fluctuating asymmetry is a relative measure. Inferences and conclusions about the level of fluctuating asymmetry in a population can only be derived by comparing it with the same measure from another population, or between different time periods in the same population. Most conservation applications for this measure are likely to involve comparisons between populations, e.g. alpine v. island-dwelling takahe, source v. translocated populations, or involve time-series monitoring, e.g. before and after treatments, between year changes etc. Therefore, the principal questions tend to be "is there a difference between.....?" or "has there been a change in.....?"

What to measure

Convincing results have been obtained from measurements of limb and cranial characters in vertebrates (fin, tail, wing, digits, long bones, skull bones, teeth), from counts of lateral plates, scales and bristles in fish and invertebrates, and from flower and leaf measurements in plants. Anything goes it seems! The choice of trait to measure should be influenced by ease and likely accuracy of measurement, especially given that many asymmetries represent differences of no more than 1-2%. Traits whose asymmetry may directly affect performance (e.g. limbs, wings) are often used but there is a danger that these could be under intense selection for symmetry which may over-ride (to some extent) the environmental influences which fluctuating asymmetry is considered to detect.

In practice, it is better to measure more than one character on each individual. A result demonstrating that two-three independent characters show a similar trend

is all the more convincing. Conflicting results across multiple characters likewise emphasise the need for some interpretative caution.

Measurement accuracy

The smaller the character being measured and the smaller the extent of the asymmetry the greater measurement error may contribute to your sample results. Unequivocal measuring points are a must, especially when dealing with live and struggling beasts in the field

Measurement error can be calculated and corrected for, but to do this you are required to repeat your measurements. Ideally, your repeat measurements should not be influenced by knowledge of those taken previously...otherwise you will subconsciously squeeze the callipers a little harder to get your measurements more similar. Palmer (1994) recommends that traits are always measured *at least* twice, but when sample sizes are small (<20) Møller & Swaddle(1997) argue that three or more repeat measurements should be taken and analyses performed using the means of each individual's multiple measurements.

Sample size

As in all sampling programmes, the larger your sample the more confident you can be that your results are representative of your study population. There are some published studies claiming profound results with samples of 10-15, which is really pushing it! The evidence from modelling studies (Palmer 1994) suggests that samples of 40 ought to be a minimum target.

ANALYTICAL PROCEDURE

Several indices have been used to describe fluctuating asymmetry within a population. Although their statistical properties are slightly different, the commonly used indices, listed below, all enjoy widespread use (see Palmer & Strobeck (1986), Palmer (1994) and Møller & Swaddle (1997: Chapt 1:10) for further explanation).

(a) $\hat{A}[(|R_i - L_i|)] / N$ – the sum of all the absolute right(R) minus left (L) values (you ignore the ± signs), divided by the sample size.

(b) $\hat{A}[(R_i - L_i)^2] / N$ – the sum of all the squared right minus left values, divided by the sample size.

(c) $\text{Var}\ (R_i - L_i)$ – the variance of all the individual right minus left values (± signs taken into account).

(d) $\hat{A}[\{(|R_i - L_i|) / 0.5(R_i + L_i)\}] / N$ – each absolute right minus left value is divided by half of its right plus left value, these are all summed, and the total divided by the sample size.

(e) $\text{Var}\ [(R_i - L_i) / 0.5\ (R_i + L_i)]$ – the variance of all the individual calculations of the right minus left values divided by half of its right plus left value.

Indices d and e differ from the others. In these, character size is scaled in each individual and they are used when there is evidence that the extent of the asymmetry is proportional to the character size.

These formulae are less frightening than their notation makes them appear. All

first require a calculation of the difference between the right and left measurements of each individual sampled. That figure is then processed, differently, as the formulae demand. In the case of indices c and e, it is the sample variance that is used as the index.....sample variance is another name for *square of the standard deviation.* Table 1 illustrates the sorts of calculations required to compute these indices

TABLE 1: SAMPLE EXCEL WORKSHEET FOR THE CALCULATION OF FLUCTUATING ASYMMETRY INDICES BASED UPON A SAMPLE OF 10 INDIVIDUALS. EACH COLUMN IS IDENTIFIED WITH A LETTER FOR LATER DESCRIPTION. RIGHT (R) AND LEFT (L) MEASUREMENTS OF THE TRAIT FOR EACH INDIVIDUAL (1 - 10) ARE LISTED IN COLUMNS. B & C

A SAMPLE NO.	B RIGHT	C LEFT	D ABSOLUTE R-L	E SIGNED R-L	F $(R-L)^2$	G (R+L)/2	H ABSOLUTE (R-L) / [(R+L)/2]	I SIGNED (R-L) / [(R+L)/2]
1	21.3	22.2	0.9	-0.9	0.81	21.75	0.0414	-0.0414
2	22.8	22.7	0.1	0.1	0.01	22.75	0.0044	0.0044
3	22.3	22.8	0.5	-0.5	0.25	22.55	0.0222	-0.0222
4	20.9	21.4	0.5	-0.5	0.25	21.15	0.0236	-0.0236
5	22.8	22.1	0.7	0.7	0.49	22.45	0.0312	0.0312
6	21.4	21.8	0.4	-0.4	0.16	21.6	0.0185	-0.0185
7	22.6	21.9	0.7	0.7	0.49	22.25	0.0315	0.0315
8	20.9	21.1	0.2	-0.2	0.04	21	0.0095	-0.0095
9	19.9	20.7	0.8	-0.8	0.64	20.3	0.0394	-0.0394
10	21.6	20.5	1.1	1.1	1.21	21.05	0.0523	0.0523
Sum			5.9		4.62		0.2217	
Variance				0.47788				0.00104

Thus, the various indices can be readily calculated:
Index (a) = Sum Col. D / sample size = 5.9 / 10 = 0.59 ;
Index (b) = Sum Col. F / sample size = 4.62 / 10 = 0.462 ;
Index (c) = Variance of Col. E figures = 0.47788 ;
Index (d) = Sum Col. H / sample size = 0.2217 / 10 = 0.02217 ; and
Index (e) = Variance of Col. I figures = 0.00104
The fact that here are five different ways of expressing the same thing need not be alarming. Just as in language we may have several different words meaning the same thing so the same applies in mathematics. All of the above indices are appropriate, but each is more appropriate under particular circumstances. Palmer (1994) gives a very thorough explanation of these. However, in the literature, indices (a) and (b) are those most frequently used.

INTERPRETATION

Having calculated an index of fluctuating asymmetry for a particular population, the next step is to interpret it relative to some other population(s). One is generally seeking to determine whether the extent of asymmetry in one population is similar to, or significantly different from, that in one or other populations, or varies over time in the same population, and this requires the use of appropriate statistical tests.

Where comparison is between two data sets, and the indices are either b, c or e above, then the most powerful test is an F-test. These indices are variances and an F-test is simply a ratio of the larger over the smaller variance. The significance of this ratio can be looked up in a statistical table for the appropriate degrees of freedom.

For the analysis of differences in fluctuating asymmetry between three or more data sets, then any of Bartlett's, F_{MAX}, Levene's, or Scheffé's tests are appropriate, with Levene's test usually being the most appropriate (Palmer 1994).

Don't be put off by the fact that some specific statistical tests are required. They are not difficult, and once you have worked your way through the full analytical procedure with the help of a numerate colleague or a statistician, you will have a clear prescription, or recipe, to follow.

LIMITATIONS AND REQUIREMENTS

It is worth repeating that fluctuating asymmetry is a relative measure. Inferences and conclusions about the level of fluctuating asymmetry in a population can only be derived by comparing it with the same measure from another population, or between different time periods in the same population.

Another essential point to note is that whatever is being measured must have undergone development during the period of exposure to the "stress". For example, if bird tarsi are being measured, their development is during the nestling period and it may be an inappropriate measure in adult birds if the stress is a very short term one or you are evaluating differences between short time periods. In organisms where development of characters proceeds throughout life, e.g. limb size, teeth, feathers, leaves, flowers, short-term stresses ought to be reflected. Similarly, if the time of exposure is greater than the generation time of the organism under study, characters of adults and juveniles can both be used.

There are also some pretty essential statistical issues to be taken into account. Space doesn't allow a full explanation of these here, but suffice to alert you to the need to ensure, before final data analyses, that your measured character does indeed show fluctuating asymmetry and not one of the other forms of symmetry (e.g., directional symmetry) common in nature (see Palmer (1994) and Møller & Swaddle (1997) for appropriate explanations).

Finally, and essentially! Fluctuating asymmetry does not tell you what the causes are of the observed changes in developmental stability. It informs you that a change is occurring or has occurred, nothing more, nothing less. From that point other investigative hypotheses and approaches need to come into play. The real utility of fluctuating asymmetry measurement is that it can provide a simple, cheap, effective, and biologically realistic means of detecting change (naturally or experimentally induced), of providing comparisons and assessments, and of acting

as an early warning system. The literature contains many examples of it being used on plants and animals alike, and in terrestrial, aquatic, and marine ecosystems.

Like all ecological evaluation techniques, fluctuating asymmetry has been subjected to considerable academic scrutiny. This is as it should be. Some theoreticians remain sceptical about the validity of fluctuating asymmetry being anything other than random developmental 'noise'. Others believe it to be soundly based in biological and statistical theory and appropriate for all sorts of evaluations. Certainly, the literature in support of fluctuating asymmetry is growing, as are the (often novel) examples of its use. It is not a technique to ignore, but nor should the reader confine their knowledge of it to this superficial article.

INFORMATION SOURCES

The most recent, and comprehensive, text on developmental stability and fluctuating asymmetry is Møller & Swaddle (1997). Written primarily for the academically inclined and those with a particular interest in evolutionary biology, this book is still an easy and enlightening read and provides an excellent over-view of the subject. It is supported by a regularly updated web site (http://www.oup.co.uk/MS-asymmetry), which contains two chapters of text originally written for the book but not included for reasons of space. One chapter is a general introduction to the study of asymmetry in science and biology, and the other is a review of possible applications of asymmetry and developmental stability in the life sciences. These web chapters are a 'must read', and the many tables at this site are also worth a scan. The web site also tracks recent literature.

There are many papers in scientific journals detailing results of fluctuating asymmetry studies, indicating applications of the method, and providing reviews. Searches of literature databases (e.g. BIOSIS) or abstracting journals (e.g. *Ecological Abstracts, Aves)* using 'fluctuating asymmetry' as a key word will quickly reveal these. There is little need to search literature earlier than 1985. *Oikos* and *Proceedings Royal Society (London): Series B* are two journals in which fluctuating asymmetry studies are particularly common. General papers that give emphasis to the use of fluctuating asymmetry as a tool for environmental monitoring, or discuss its application in conservation management include Leary & Allendorf (1989), Parsons (1992), Clarke (1993, 1994, 1995), Sarre et al. (1994), and Tracy et al. (1996).

It is well worth searching the web for sites dedicated to fluctuating asymmetry research and application. Try two or three different search engines using 'fluctuating asymmetry' as your search topic. Many researchers have their own home pages on which they post all their manuscripts (published and unpublished), and provide links to other sites covering the same topics. One personal site to visit is that of A.R. Palmer (http://gause.biology.ualberta.ca/palmer.hp/asymmetry.htm) from which you can download a spreadsheet that computes a range of fluctuating asymmetry statistics. From his PubList.htm address you can receive his primer, an essential read and containing many useful suggestions for analysing fluctuating asymmetry data at the population level (Palmer 1994). The latter is a pdf file so you will need access to Adobe Acrobat Reader to print it out.

POSTSCRIPT

This article is intended as a brief explanation of fluctuating asymmetry and how it can be used to support conservation management *at the population level.* But just as a population comprises many individuals, so the index of fluctuating asymmetry for a population is derived by measuring the asymmetry of individuals. This has led to investigation of fluctuating asymmetry as a measure of *individual* fitness or quality; the more symmetrical the individual animal or plant, the better its quality and likely reproductive legacy. Møller & Swaddle (1997) summarise many of these studies, for example:

(i) symmetry of an individual swallow's tail determines the speed with which it attracts a mate, the timing of its breeding and its subsequent breeding performance;

(ii) swallow wing symmetry determines ability to avoid objects and collisions, catch prey and avoid predation from hawks; and

(iii) dominant blackbirds with the better quality territories and higher breeding output are the more symmetrical individuals.

There is still a vigorous academic debate about fluctuating asymmetry as a measure of individual quality. If you hear or read criticism of fluctuating asymmetry it is generally about its use as a measure of individual quality. Yet some of the studies supporting its use at the individual level (as in Møller & Swaddle 1997) are very convincing. Where conservation management is applied at the individual level, as it is in many recovery programmes for rare and endangered plants and animals, it would be foolish to ignore the potential of fluctuating asymmetry measurement to contribute to decision-taking and monitoring procedures.

ACKNOWLEDGMENTS

I was alerted to the potential usefulness of fluctuating asymmetry measurements to conservation issues when listening to Luc Lens at the 22nd International Ornithological Congress describe using it to evaluate bird habitat quality (Lens et al.1999; example 1 above). I acknowledge his subsequent help, comments and advice about the value of the technique. Parts of this text have been lifted directly, or slightly modified, from that of Clarke (1995). I thank Harry Keys, Carol West, Wayne Hutchinson, and Susan Dobson for comments on an early draft of this article.

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Transfer of toutouwai (*Petroica australis longipes*) from Mokoia Island to Moturoa Island

Keith Owen[1] and Paul Asquith[2]

[1.] Bay of Plenty Conservancy, Department of Conservation, P.O. Box 1146, Rotorua.
[2.] Moturoa Island Limited, 56 Rothesay Bay Road, Auckland 10.

ABSTRACT

The toutouwai, or North Island robin (*Petroica australis longipes*), is an endemic passerine found in central North Island forests and on Hauturu (Little Barrier), Tiritiri Matangi, Mokoia, Kapiti, and Mana Islands.
Nineteen toutuowai were captured on Mokoia Island, and transferred to Moturoa Island, Northland, on 2 June 1999. This is the third population of toutouwai currently in Northland.

INTRODUCTION

Toutouwai, were once widely distributed in forests of the North Island and on Hauturu and Kapiti Islands at the time of European settlement. They disappeared from the northern and southern parts of the North Island in the early 1900s (Heather and Robertson 1996). The toutouwai is considered to be regionally threatened (Bell 1986).
The species is now restricted to central and western North Island native and exotic forests and Hauturu and Kapiti Islands (Turbott 1990). It was introduced to Mokoia Island in Lake Rotorua in June 1991 (Jansen 1993) and to Tiritiri Matangi and Mana Islands more recently.
In March 1997, a toutouwai transfer proposal, prepared by Mike McGlynn of the Russell Field Centre of Department of Conservation (DOC), was approved by the Species Protection Division of Head Office, DOC. The proposal sought to transfer toutouwai from Mokoia Island to Moturoa Island. If successful this would be the third population of toutouwai in Northland and would allow the island population to become a source of toutouwai for future Northland transfers. Trounson Scenic Reserve and Moturua Island, the two Northland sites, have small populations of toutouwai so were considered inappropriate as potential sites to remove birds. Mokoia was selected as the next best option because it holds a large population of toutouwai (Owen 1997) and is easily accessible.

MOTUROA - RECIPIENT ISLAND

Moturoa Island, a Wildlife Refuge gazetted in 1960, is owned by a group of 20 shareholders. Moturoa, approximately 140 ha in area, is situated in the inner Bay of Islands, Northland. It lies approximately 400 m north east of Day Point and 1600 m south east of Poraenui Point, which are the closest mainland headlands.

About 45 ha of kanuka shrubland/forest and coastal broadleaf forest has been retired from grazing, fenced and is available as habitat for forest wildlife. This includes small exotic forestry woodlots that are utilised as habitat by wildlife. The remaining 95 ha is farmed solely with sheep.

Over the last 20 years the owners have planted over 40,000 native trees and shrubs, developed and extended wetlands, and have significantly reduced weeds with an ongoing monitoring and eradication programme as part of a long-term restoration project (Asquith 1999). Rat and stoat control has taken place since 1993. Norway, ship and kiore rats are at very low levels (Taylor 1989) or are absent, although 1 Norway rat was caught on the island in February 1999. Although an unconfirmed stoat sighting has been reported, there have been no stoats trapped since 1993. Although stoats are likely to occasionally swim to the island, ongoing trapping and established bait stations deal with invaders and keep the rat population low. Since the 1980s the owners have introduced North Island brown kiwi, kakariki (red-crowned parakeet), pateke (brown teal), tieke (North Island saddleback), and moho-pereru (banded rail).

MOKOIA - SOURCE ISLAND

In June 1991 toutouwai were successfully introduced to Mokoia Island from the Mamaku Plateau and the National Wildlife Centre near Masterton. The founder population was 17 birds, 7 males and 10 females (P. Jansen pers.comm, Jansen 1993). The population is now well established, and because it numbers about 200 birds (Owen 1997) it can be cropped for transfers to other locations from time to time.

Mokoia Island was considered the most appropriate site to remove toutouwai from because it had a healthy population (thus surplus birds were available), the site was easily accessible (compared to other central North Island sites), and the Mokoia Island Trust approved the removal of up to 20 birds.

CAPTURE OF BIRDS

On 1 June 1999, a team of six people boated to Mokoia Island in Lake Rotorua. Two capture teams of three people initially located and marked toutuowai territories in the southern and eastern sectors of the island, and at 11.30 a.m. commenced capturing birds.

To capture birds, the teams used battery-operated clap traps. Toutouwai were attracted to the vicinity of clap traps by creating noise, often by clapping hands or broadcasting short bursts of taped toutouwai calls. Once at the capture site the toutouwai were fed commercially cultured mealworm (*Tenebrio molitor*) or waxmoth (*Galleria mellonella*) larvae on the ground in front of the trap. The

release system was operated when a bird was at the correct spot to be captured as it retrieved a mealworm.

By 16.15 p.m. 12 birds had been caught, metal banded, and placed into transfer boxes. Each box had 2 birds, but each bird was in an individual compartment. They were offered mealworms, waxmoths, chopped earthworms, and water. The boxes were left overnight in a hut on the island in a quiet area.

The next day (2 June) a further 7 birds were caught by 10.00 a.m. Thus a total of 19 birds were captured of which 6 were 3 pairs, but sexing the others was difficult especially five juveniles. The likely sexes of the birds were 7 males, 7 females and 5 juveniles (sexes unknown). Monitoring this breeding season should indicate the sexes of each bird that we were unsure of or did not know.

TRANSFER OF BIRDS

Before departure from Mokoia at 10.15 a.m. on 2 June, the 19 birds were offered food and water in their transfer boxes. After an 10-minute boat trip across Lake Rotorua and a 15-minute car trip to Rotorua Airport the birds, in 10 boxes, were loaded into a Cessna aircraft. The plane departed at 11.35 a.m. reaching Kerikeri in the Bay of Islands at 13.35 p.m. A further car and boat trip resulted in the birds arriving safely at Moturoa Island by 14.35 p.m.

By 15.30 p.m. all birds had been released. Known pairs were released at the same location. Ten birds were released at Ponga Hollow, and 9 birds at Trout Valley, near the centre of the island. All flew strongly on release.

It appeared that the birds fed well while in captivity because stocks of larvae in the transfer boxes were depleted by the time the birds were released. There was a slight preference for waxmoth over mealworm larvae, and some earthworm pieces were eaten. A total of 1000 waxmoth and 2000 mealworms were used over the 2-day period as bait and food for toutouwai.

A few days after release 17 birds were located with some birds dispersing away from the release site.

MONITORING

The birds will be monitored periodically by the owners who intend to report on the outcome of the forthcoming breeding season in March 2000. Monitoring will indicate how widely the birds disperse from the release sites and the number of fledglings produced during the breeding season.

ACKNOWLEDGEMENTS

As well as the authors, participants in the capture were Enid Asquith of Auckland, Richard Griffiths (DOC), Greg Moorcroft and Daniel Van de Lubben from Rotorua. We thank them for their assistance.

Boat transport on Lake Rotorua was provided by Rotorua Lakes Area Office (DOC). Andrew Knight of Volcanic Wunderflights, Rotorua, flew the aircraft. Ian Faulkner,

and Colin and Marion Cameron provided boat and car transport at the Bay of Islands.

Mike McGlynn wrote the transfer proposal. Richard Parrish of Whangarei Area Office, DOC assisted with arranging permits. Bill Kingi and Selwyn Bennett of Mokoia Island Trust provided permission to catch and transfer toutouwai from Mokoia.

Ralph Powlesland commented on the manuscript.

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Iwi initiated introduction of tieke to Moutohora (Whale Island)

K. L. Owen[1] and A. Blick[2]

1. Bay of Plenty Conservancy, Department of Conservation, P.O. Box 1146, Rotorua.
2. Rangataiki Area Office, Department of Conservation, P.O. Box 114, Murupara.

ABSTRACT

The tieke, or North Island saddleback (*Philesturnus carunculatus rufusater*), is an endemic forest passerine. It is currently found on Mokoia Island in Lake Rotorua and on a number of outlying islands off the northeast coast of North Island, New Zealand. This transfer of tieke was consistent with the objectives of the draft Moutohora Island Conservation Management Plan (Hunt 1992).

Forty tieke were captured on Repanga (Cuvier) Island, and transferred to Moutohora (Whale) Island on 12 March 1999. Ngati Awa (Whakatane) were involved with the proposal and assisted with the capture and transfer. Ngati Hei (Whitianga) allowed their taonga to be transferred and assisted with the capture.

INTRODUCTION

Tieke, once widely distributed in forests of the North Island and on the larger outlying islands at the time of European settlement (Turbott 1990) is now restricted to about 12 islands off the north-east coast of New Zealand (Lovegrove 1996).

Conservation of tieke has depended on island releases, because they cannot coexist with carnivores introduced to mainland New Zealand (King 1984 in Lovegrove 1996). Predation by cats, rats, and mustelids introduced by Maori and Europeans, and habitat destruction were the main causes of tieke decline.

Tieke is ranked as a Category C threatened species for conservation action by DOC (Molloy and Davis 1994).

Moutohora (Whale Island) near Whakatane was selected as a suitable island to establish a second island population of tieke in the Bay of Plenty. Tieke had previously been released on to Mokoia Island, Lake Rotorua, in 1992 and now number about 200 birds.

The draft Conservation Management Plan for Moutohora identified tieke as one of the priority fauna species for introduction (Hunt 1992).

Historic reports indicate that tieke were found throughout the Bay of Plenty, including Whakatane District. It may have been present on Moutohora in the past when the island was probably connected to the mainland (Patrick 1996).

Tieke were first considered as a potential candidate for introduction to Moutohora in 1989, but it was considered that until further areas of vegetation had regenerated

into scrub and young forest that the island was unsuitable (Owen 1989). Owing to the spectacular pace of regeneration the island was suitable for tieke introduction by 1998.

The proposal to transfer tieke to Moutohora was initiated by "Te Komiti Taiao o Ngati Awa", the Environment and Cultural Committee of Ngati Awa, in the hope that the traditions pertaining to the arrival of the Maatatua waka would be rekindled and brought to life.

According to Ngati Awa tradition, the Maatatua waka on its voyage from Hawaiki landed at Whangaparaoa, in the Eastern Bay of Plenty The waka then voyaged northwards and it was at Repanga (Cuvier) Island that the twin sons of the sister of the Chief and Captain of the waka drowned. As a result a rahui was declared. Since then the island has been regarded by Mataatua waka as its traditional boundary. The waka then turned south and landed at Kakahoroa (Whakatane). Prior to its departure from Repanga, two tieke joined the waka for the journey to its final destination. These two tieke were called Mumuhau and Takeretou, and after the waka arrived at Kakahoroa they settled on Moutohora for a brief period before flying back to Repanga. According to this tradition, the island was named Repanga in memory of one of the twins.

On this cultural basis it was entirely appropriate that the source island for tieke was Repanga and Moutohora was the recipient island. This is consistent with the following sections of the vision for future management of Moutohora as set out in its draft Conservation Management Plan (Hunt 1992):

- That ecosystems and species groupings are restored close to a pre-human state and Moutohora is a haven for indigenous plants and animals,
- A place where people may visit to admire some of the special natural gifts and cultural history, provided impacts are minimised, and
- The Department and Bay of Plenty Conservation Board have a partnership with Ngati Awa in the management of Moutohora.

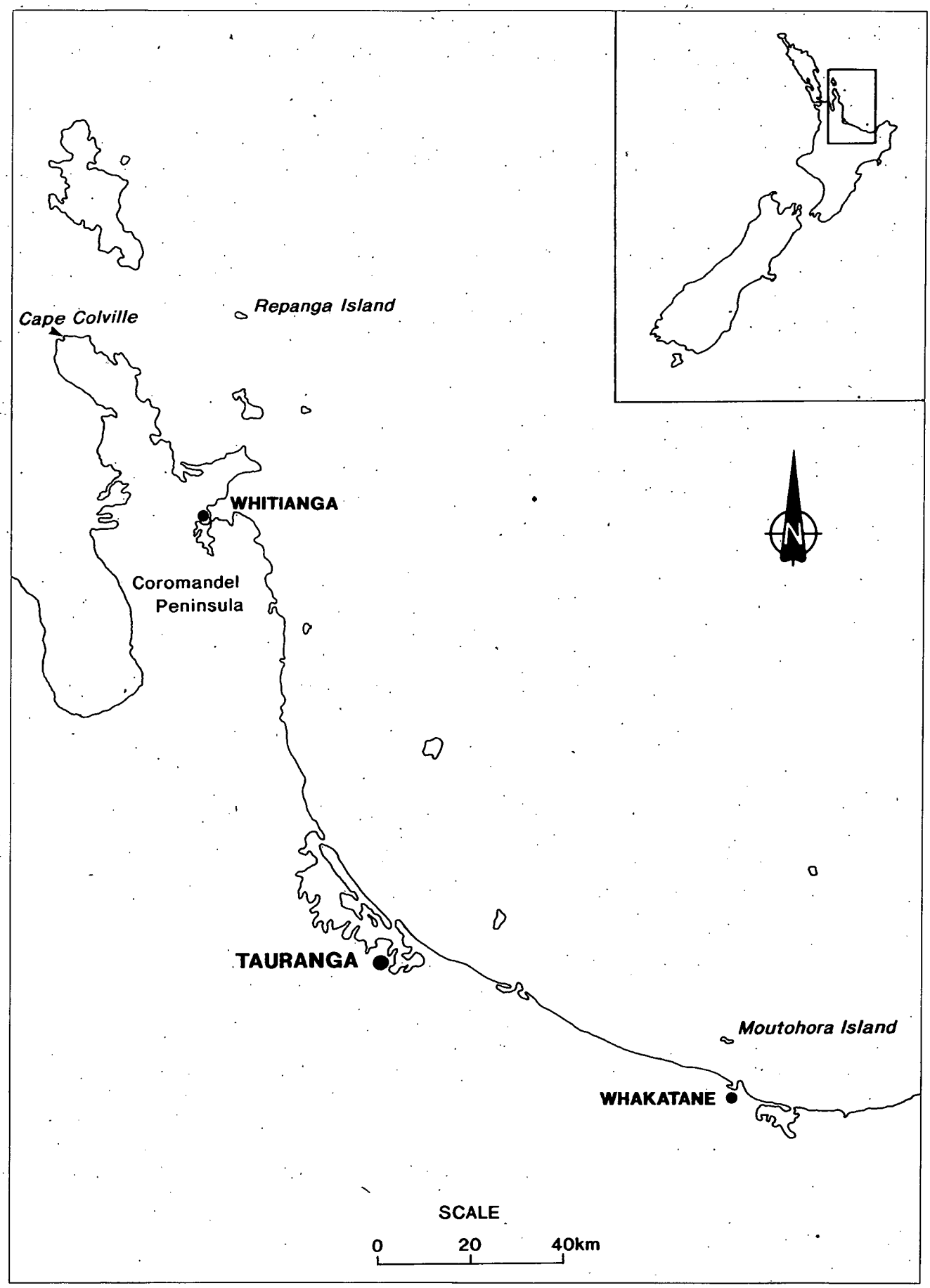
A transfer proposal (Bay of Plenty Conservancy) sought to capture and transfer 40 tieke to Moutohora during Sea Week in March 1999 (Owen, 1998). The transfer proposal was approved by the Northern Regional Manager in late 1998. All other necessary departmental consents and approvals required for capture and transfer were granted prior to the operation taking place.

SOURCE POPULATION

Repanga Island, a 194-ha nature reserve lying 38 km east of Cape Colville, Coromandel Peninsula was the source island for tieke (Figure 1). Repanga, lying 190 km northwest of Moutohora, has been formed from the eroded remnants of Miocene volcanic diorite (Towns et al 1998). It is covered with coastal pohutukawa broadleaf forest and residual ungrazed pasture (one quarter of the forest was removed for a lighthouse settlement farm in about 1889).

Waikato Conservancy manages Repanga under the Hauraki Gulf Maritime Park Management Plan as a 'sanctuary'. Tieke were introduced to Repanga Island in 1968 from Taranga Island in the Hen and Chicken Island group and now number about 1000 birds (Lovegrove 1996, Jason Roxburgh pers. comm.). Repanga is free of browsers and predators following the eradication of cats in 1960, goats in 1961 and kiore in 1993. The vegetation is recovering well since the goats were removed, and a stock-proof fence was erected in 1963 to protect the forested northern part of the island from grazing stock.

FIGURE 1: LOCATION OF REPANGA AND MOUTOHORA ISLAND



Currently, the annual juvenile crop of tieke is about 200 birds, and the island's population is close to carrying capacity (Jason Roxburgh pers. comm.). It was therefore an ideal island to remove tieke from because the 40 birds will be replaced within one breeding season.

CAPTURE RESULTS

On 5 March, after Ngati Hei provided mihi, parakuihi, and karakia at Whitianga, the capture team of 10 people was taken by helicopter to Repanga Island. Over the next 3 days 36 mist nets were set up at numerous sites along Shooters Ridge and North-west Bay Tracks in regenerating pohutukawa forest where habitat was suitable for tieke. Three teams of three people made up the capture teams with Dick Veitch sexing, weighing, and banding the birds as they were caught.

Forty tieke (20 males and 20 females) were caught, plus 6 surplus males were caught and released. The captures took 12 hours spread over 3 days. Each bird was sexed according to tarsus length (Jenkins and Veitch 1991), weighed and banded with a unique combination of a metal and two colour bands (Appendix 1). Three previously banded birds were caught and retained, each of them being over 10 years old.

During the mist netting a record was kept of all birds caught. Apart from the 46 tieke caught 167 non-target birds were caught. This consisted of 101 makomako (bellbird), 34 kakariki, 20 piwakawaka (North Island fantail), 11 riroriro (grey warbler), and 1 blackbird.

Once captured, the tieke were carried in transfer boxes to the aviary set up in a room in "No. 3 house". This room, prepared during an earlier trip by Rob Chappell, was made more comfortable by adding chicken mesh and shade cloth to the windows. The team added perching branches and leaf litter before to the captured birds were released into the aviary. Food supplied to the captured birds was as described by Lovegrove and Veitch (1994). Of these, jam-water and mealworms proved to be the most popular foods. Jason Taylor, who managed the aviary, reported observing males courtship-feeding females, and juveniles begging for food and being fed by adults.

Adult weights were slightly higher and juvenile weights slightly lower than the average data given by Jenkins and Veitch (1991).

TRANSFER

On the morning of 12 March the aviary held birds were placed in transfer boxes with food and water and taken to the helicopter-landing site below the main house. All of the team and the tieke in transfer boxes were flown to Whitianga in two flights, after which the helicopter carried on to Moutohora with the birds and three team members.

Moutohora (Whale) Island Wildlife Management Reserve, the release site, lies 6 km off the Whakatane coast (Figure 1). The 143 ha island is a steep, remnant andesite volcano covered with a mosaic of pohutukawa forest, mahoe forest, kanuka shrublands, bracken, and rank pasture grasses (Hunt 1992). It has no introduced browsers and predators because cats, Norway rats, and rabbits were all eradicated (Hunt 1992).

On arrival at Moutohora the 40 tieke were released after a mihi (welcoming ceremony), on the southern side of Pa Hill near Te Puna Wai. In attendance was a large contingent of Ngati Awa (tangata whenua), DOC staff, Ngati Hei (donor) representatives, and the media (TV and press). The tieke capture on Repanga and their release on Moutohora were recorded on video by Lindsay Canham of the department's former video unit.

No artificial nest or roost boxes were set up on Moutohora, as is often done prior to new island releases of tieke. After reviewing the survival of past tieke releases on other islands, and from discussions with Tim Lovegrove, it was considered that the birds should cope with being released directly on to Moutohora, this being carried out within 2 hours of their arrival on the island.

The estimated carrying capacity of tieke on Moutohora is between 500-1000 birds, a viable population given that smaller islands with similar ecosystems have thriving populations of tieke on them (Lovegrove 1996). With food for tieke available all over Moutohora, the released birds should do well and establish throughout the island.

MONITORING

Post-release monitoring of transferred fauna to determine the outcome of transfers has been widely accepted as an important task of establishing a population by transfer, especially involving releases on offshore islands (Pierre 1999). Auckland University students will monitor the released birds during the 1999/2000 breeding season with assistance from the department.

The key criteria in determining if the transfer has been successful will be the development of a self-sustaining population of tieke on the island within the next 5 years (Owen 1998).

Mike Fitzgerald is studying the impacts of the released tieke on the spider fauna of Moutohora. This research should provide an insight into the impacts that tieke may have on the spider fauna of northern islands of New Zealand.

PUBLIC SUPPORT

The public has been fully supportive of the transfer, because tieke are a threatened endemic species and there was a desire to see them introduced to Moutohora. The transfer will give the public the opportunity to view tieke because one of the Moutohora Island Conservation Plan objectives provides for " limited public access and increased education and interpretation through managed access "(Department of Conservation 1999).

ACKNOWLEDGEMENTS

The success of this operation was very much a team effort. Besides the authors, participants in the capture and transfer operation were Anaru August, Lindsay Canham, Rapata Kopae (Ngati Awa), Scott McLean (Ngati Hei), Elizabeth Price, Jason Taylor, Bob Watters, and Dick Veitch. We thank them all.

A big thanks to Ngati Hei for approving the transfer and their mihi at Whitianga and to Ngati Awa for providing the inspiration and support for the transfer. Tim Lovegrove and Dick Veitch provided expert advice. Shaarina Boyd provided capture equipment and transfer boxes, and Rob Chappell constructed the aviary. Jason Roxburgh and the Hauraki Area staff provided valuable information and advice. The logistic support they gave was invaluable. Rick McGovern-Wilson and Ralph Powlesland provided comments on a draft of this paper.

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APPENDIX ONE: DATE CAUGHT, AGE, SEX, TARSUS LENGTH (MM), WEIGHTS (G) AND BAND DETAILS OF TIEKE TRANSFERRED TO MOUTOHORA ISLAND

DATE CAUGHT	AGE	SEX	TARSUS	WEIGHT	COLOURS	BAND NO.	COMMENTS
7/3/99	J	F	39.2	66	RW-M	173201	
	J	M	42.0	74	RB-M	173202	
8/3/99	J	M	40.8	75	RY-M	173203	
	A	F	38.2	74	RG-M	173204	
	A	M	40.1	79	WR-M	173205	
	A	M	41.2	84	WB-M	173206	
	J	F	38.1	62	WY-M	173207	
	A	M	40.8	84	WG-M	173208	
	A	M	41.9	87	M-RW	127098	Was YM-G or MY-G
	J	M	41.8	75	BR-M	173209	
	A	F	38.0	69	BW-M	173210	
	A	F	38.4	72	BY-M	173211	
	J	F	39.8	70	BG-M	173212	
	A	F	38.1	68	YR-M	173213	
	A	F	38.5	72	YW-M	173214	
	A	M	40.4	77	YB-M	173215	
	J	M	40.9	79	YG-M	173216	
	A	M	41.6	86	GR-M	173217	
	J	M	41.4	81	GW-M	173218	
	J	F	38.1	68	GB-M	173219	
	A	M	41.7	80	GY-M	173220	
	J	M	41.0	83	M-RB	173221	
	J	M	41.4	76	M-RY	173222	
	Imm	F	39.0	74	M-RG	173223	
	J	M	41.7	80	M-WR	173224	
	A	M	41.9	82	M-WB	173225	
	A	F	36.6	72	M-WY	173226	
	A	F	37.9	77	M-WG	144023	Was MB-RB or MB-BR
	A	F	39.1	76	M-BR	173227	
	J	M	40.6	75	M-BW	173228	
	A	F	38.9	70	M-BY	173229	
	A	F	38.3	70	M-BG	173230	
	J	M	37.2	69	M-YR	173231	
	A	M	41.8	77	M-YW	143601	Was MG-G
	A	F	38.9	74	M-YB	173232	
	J	M	41.5	76	M-YG	173233	
	J	M	41.3	80	M-GR	173234	
	Imm	F	37.4	64	M-GW	173235	
9/3/99	J	F	37.1	64	M-GB	173236	
	J	F	36.6	59	M-GY	173237	

Pitfall trapping for long-term monitoring of invertebrates

Chris Green

Department of Conservation, Private Bag 68-908, Newton, Auckland
E-mail cgreen@doc.govt.nz

ABSTRACT

Long-term monitoring studies of invertebrates require the use of a robust method of invertebrate collection which is systematic, repeatable, easy to use, and provides adequate numbers of specimens for analysis. Pitfall trapping is one such method, and all aspects in relation to a long-term monitoring programme are described in detail, including planning a programme, choice of trap design, setting up, trap clearance and maintenance, sorting and identification of the invertebrates, and analysis to look for long-term trends. Advantages and disadvantages of pitfall trapping are discussed. The aim is to present the method so it can be picked up and used by workers with little or no background in entomology.

INTRODUCTION

In New Zealand conservation work there have been a wide variety of programmes involving eradication or control of exotic vertebrate predators, including rodent eradication from islands (Veitch and Bell 1990, Towns and Ballantine 1993, Mansfield and Towns 1997, Adams 1995, McKinlay 1999) and control of predators from mainland sites (Saunders and Norton in press). Predators known to feed on invertebrates include ship rat, Norway rat, kiore (Polynesian rat), mouse, stoat, weasel, ferret, cat, hedgehog, and possum (King 1990). Indigenous New Zealand invertebrates have evolved without the presence of such predators, and species which appear most susceptible to predation tend to be large bodied, flightless, often ground-dwelling and nocturnal, such as many species of weta (Gibbs 1998).

In order to determine what effects these predators have on populations of invertebrate long-term monitoring studies are required. Since most of these predators spend much of their time hunting on the ground a monitoring technique which targets ground-based invertebrates is most suitable. Pitfall trapping is one technique that has been widely used to study such fauna (Lövei and Sunderland 1996).

Pitfall traps essentially operate by catching those invertebrates that fall into a hole in the ground. They depend on the invertebrate moving to the trap prior to falling into it. Therefore, pitfall traps are a measure of invertebrate activity, and the greater a species moves, both frequency and distance, the greater the chance it will be caught. Highly active predators, such as centipedes, large vagrant spiders, and ground beetles (Carabidae), generally have a greater chance of being caught than slower, less mobile species such as millipedes, woodlice, or smaller spiders.

A wide variety of techniques have been described for surveying and monitoring of invertebrates (Southwood 1978, Green 1996 and New 1998). The present paper expands on pitfall trapping as one technique and is designed so that workers with little or no experience in collection of invertebrates can undertake monitoring programmes, although involvement of an experienced entomologist in the planning stages is recommended. An entomologist may also be required to assist with identification of the species trapped and their availability should be confirmed prior to beginning a monitoring programme.

PLANNING A MONITORING PROGRAMME

Aims

Before planning the details of the programme the aims or goals of the monitoring study must be decided, especially if it is part of a larger study involving other disciplines, to ensure that pitfall trapping is an appropriate technique for the desired outcomes. Pitfall trapping is appropriate for a monitoring study that aims to identify changes in numbers of ground-dwelling invertebrates over time after some treatment has taken place. Treatment may be a change in management such as the eradication of a predator from an island or pest control at a site on the mainland. If treatment involves control (versus eradication) of a predator then it is important to have a parallel, contemporaneous predator monitoring programme in place. The latter, together with adequate weather recordings, may be vital in understanding possible causes of the changes in invertebrate populations following the treatment or management action.

When considering the aims of the monitoring study the length or time-scale of the programme should also be considered. The full effects of management actions, such as predator control or eradication, may take many years to be reflected in changes to invertebrate populations. In general terms, monitoring for 2 years prior to the treatment, then for a further 3 years post treatment should be sufficient to demonstrate some of the more immediate changes. Therefore planning should allow for a 5-year programme at a minimum. However, trapping need not be continuous throughout the period, but undertaken on a seasonal basis (see later section "Duration of trapping").

Data interpretation

While data from pitfall traps will take the form of numbers caught care must be taken not to interpret these numbers as a measure of absolute density of a species, (Sunderland et al 1995) except under controlled situations where a second method has been used to check and calibrate the pitfall results (Hayes 1970, Baars 1979, Topping 1993, Mesibov et al 1995, Ulber and Wolf-Schwerin 1995). However, there may be exceptions for some species at some sites (Anderson 1991, Thomas and Sleeper 1977). The efficiency of pitfall traps in collecting invertebrates will vary from micro-site to micro-site and from one species to another. While some individuals may fall into the trap others of the same species may not (Greenslade 1964, Luff 1975, Adis 1979, Halsall and Wratten 1988, Benest 1989).

The main assumption made for the pitfall trapping method to be valid, as a long-term monitoring tool, is that as many variables as possible should be cancelled out, except time and the treatment effect. Therefore, it is important that the site of

each trap remains exactly the same between each sampling occasion. Similarly, the habitat around the trap sites should be relatively uniform and remain relatively constant, although it may vary with time as a result of natural changes in the ecosystem. This is required so that the effect of the treatment will be easier to identify above the natural variations in, for example, weather which can have a significant affect on the level of activity of most terrestrial invertebrates (see section "Weather recordings" below) and thus the numbers caught in pitfall traps.

Most invertebrates have seasonal activity patterns and will be in different life history stages (i.e. egg, larva or nymph, pupa, or adult) at different times of the season or year. This needs to be taken into account when looking for changes in populations after some form of treatment. Therefore, in general, samples should only be compared if taken from the same relative time of the season or year. For example, invertebrates collected during November should only be compared to those collected in November in other years, December with December etc. Exceptions could occur if it could be demonstrated that the season started much earlier or later than expected and thus changing the relative calendar month.

EXPERIMENTAL DESIGN

After deciding that pitfall trapping and the data it will yield is appropriate for the aims of the monitoring programme there are several aspects of experimental design, which should be considered. The design must take account of site variation, include treatment and non-treatment sites, duration of trapping, number of traps, and trap layout. However, the first consideration must be how the data is to be analysed. Spurr and Powlesland (in press) have a very useful discussion of various aspects of experimental design, replication, randomness, and appropriate analysis methods for monitoring studies, including pitfall trap studies.

Analysis

When planning the monitoring programme it is important to consider how the information will be analysed so that there is statistical confidence in the observed outcome. Therefore, the experimental design of the trapping programme must be tailored to fit particular analysis methods. The aim here is to produce data that has a normal distribution so that statistical methods such as analysis of variance (ANOVA) (Underwood 1997) (also available in the statistical package SPSS used throughout DOC) can be used. Variables would be time and treatment for a two-way ANOVA for each species or invertebrate group. However, in some instances even the best design will produce data that will require non-parametric methods of analysis, such as Kruskal-Wallis ANOVA (Underwood 1997).

These methods all have assumptions, and the most appropriate method for use will depend on the assumptions which are violated, for example, assuming the data is normally distributed when, in fact it is not. Generally non-parametric tests will cover most of the data characteristics. Both parametric and non-parametric methods require the data to be independent, which in the present context means each pitfall trap or replicate of traps must be far enough away from the others to ensure that the sample it takes of the population is not influenced by samples taken by other traps nearby (see "Trap layout" section below). Also, the traps may be randomly or systematically located within both the treatment and non-treatment sites, although

in practice this may be difficult to achieve if the habitat has constraints such as areas of steep slope or large tree roots limiting the sites available for pitfall traps. The experimental design should incorporate some element of random selection, e.g. the start point of a transect of pitfall traps could be chosen at random, then the rest of the transect positioned systematically.

Independence and randomness go hand in hand in any experimental design in monitoring studies. As well as independence and a normal distribution a third assumption for parametric ANOVA to be appropriate is that the data should have equal variances. Non-parametric methods do not require a normal distribution or equal variances but do require independence. A statistician should be consulted during the experimental design stage of planning the monitoring programme to check which method of analysis is appropriate.

Site variation

It is important to reduce, as much as possible, the variation in the site to be sampled and thus increase confidence in the result. Therefore, each site should consist of just one habitat type, for example if it is a forest habitat it should be one vegetation type, say kauri forest, mountain beech forest, podocarp forest etc. These broad vegetation types are likely to have different invertebrate faunas and thus should be monitored separately in order to cut down variation.

Even within a single vegetation type there will still be variation associated with different micro-site characteristics. For example, different trees contributing different litter characteristics: different ground cover plants providing good or bad hiding places; open areas versus areas covered with ground cover plants; position of fallen logs or branches; piles of litter versus bare areas; variation in slope and aspect; different patterns or shapes of the ground producing channels for water run-off; and different substrates or soil types. All these factors could be important in determining why species of invertebrates live in some places and not others. Thus multiple sampling or replication within sites is required in the sampling method to encompass this variation.

In addition to replication within a particular habitat type it is an advantage to replicate the trapping programme in more than one habitat to determine if the changes seen occur throughout the treated area. Therefore, it is advisable to have at least two replicated sample sites within the overall treated area, with each of these sites being different habitat types. Thus, for example, within the area where predators have been controlled monitoring should occur in several forest types and within each forest type there will be several groups of traps to provide the replication within that habitat type.

Treatment and non-treatment sites

It is also advisable to monitor at least one site in a non-treatment area. There must be sufficient distance between the non-treatment area and treatment area to ensure independence, i.e. that the actual treatment will not affect the untreated area. The monitoring site in the non-treatment area must have as near identical habitat type, altitude, aspect, substrate, and climatic characteristics as the treatment area. This should allow the effects of the treatment (e.g. eradication or control of rodents) to be separated out from other effects, particularly weather. Weather can have a significant effect on trap catch thus it is critical to ensure it is the same at both treatment and non-treatment monitoring sites. One of the main reasons for having non-treatment sites is to discount the effects of weather.

Monitoring sites within habitat types in both treatment and non-treatment areas must have sufficient buffering from neighbouring habitat types with different characteristics. Within a forest block a buffer of 50 m between habitat types should be sufficient. If the site is near a forest edge then a greater distance should be allowed, with traps being greater than 100 m away from the forest edge. The main reason for this is that climatic factors, particularly wind, tend to be more extreme closer to the edge. Exposure to wind leads to reduced humidity thus the forest litter can be more prone to desiccation which will lead to reduced numbers of ground-dwelling invertebrates.

The experimental design can be improved further by monitoring populations in both the treatment and non-treatment areas before and after the treatment, preferably for a period of at least 2 years or seasons prior to the treatment. This will provide a history of the invertebrate populations to act as a basis of a before and after treatment comparison.

Number of traps

The number of traps required to provide a satisfactory level of confidence in the results depends on the amount of variability present at the site. As indicated above such variability could result from micro-site factors in the immediate vicinity of the traps as well as variability on a larger scale in vegetation type within the habitat. It is often difficult to estimate the degree of such variability within the treatment and non-treatment areas and how that may influence trap catch. A power analysis (Underwood 1997) (also with the statistical package SPSS used throughout DOC) is the preferred method to determine the number of traps required. Failing this, and to err on the side of caution, 20 traps per site should be adequate in most situations.

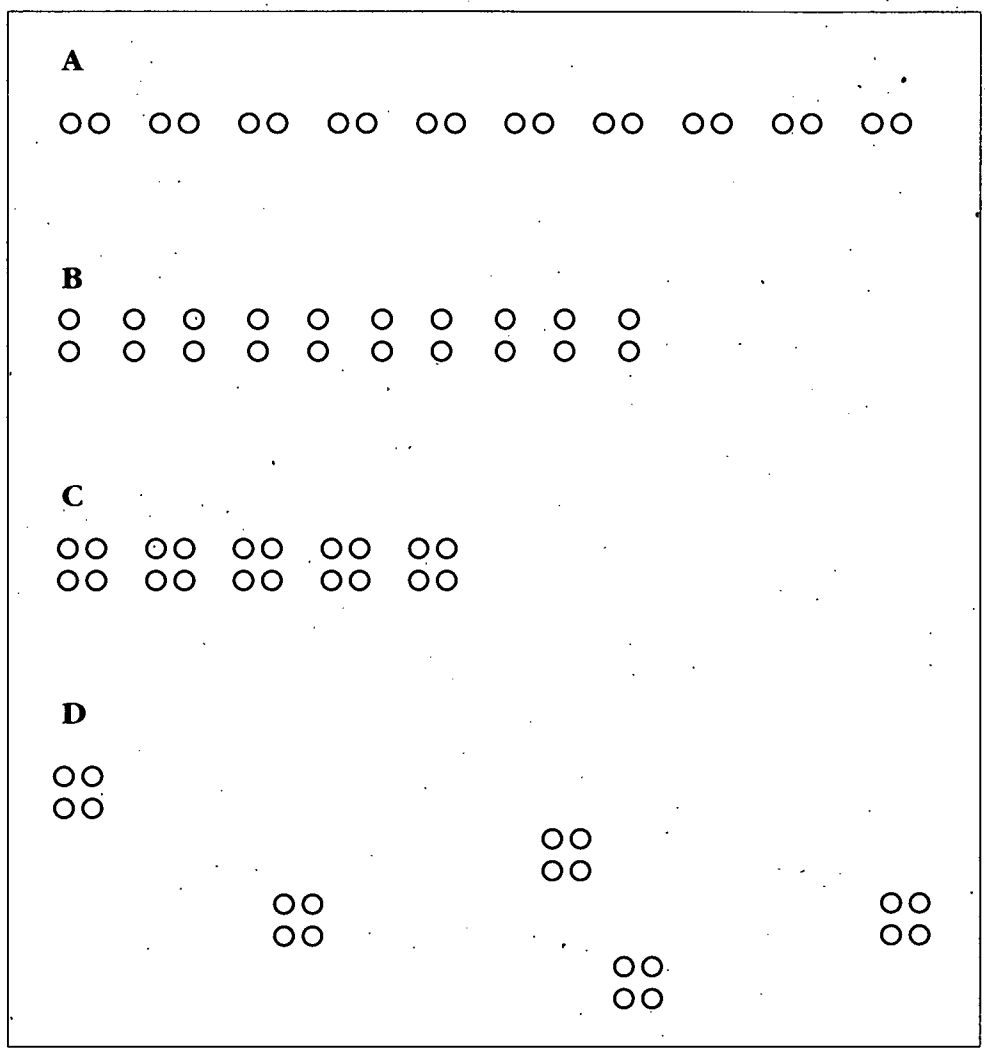
After running the traps for several seasons, post treatment, it may be possible to reduce the number of traps if power analysis shows that such reduction would not significantly reduce confidence in the results.

Trap layout

When designing the trap layout it is important to ensure independence between each sample unit or replicate. Each replicate could be an individual pitfall trap or a group of several traps. In order to reduce variance between replicates it is advantageous to have several traps per replicate. The site of each replicate within the habitat should be randomly selected and should be at least 10 m apart. Similarly each trap site within the replicate should be randomly chosen and traps be at least 5 m, but preferably 10 m, apart.

Trap layout could be set up in several ways, depending on the available area of consistent habitat. One method is to place the 20 traps in pairs along a transect with 10 m between each pair and 5 m between each trap in the pair (Figure 1A and 1B), thus 10 replicates of data are produced. Alternatively the 20 traps could be laid out in five groups of four, with at least 5 m between each of the four traps in a square or quadrat formation (Figure 1C and 1D). In that case there would be five replicates. The layouts in Figure 1 are systematic (see "Experimental design" section above) although the position of each replicate in 1D could be chosen randomly.

FIGURE 1: EXAMPLES OF FOUR TRAP LAYOUTS OF 20 PITFALL TRAPS: A, 10 PAIRS LAID OUT ALONG A TRANSECT LINE, EACH PAIR BEING A REPLICATE; B, 10 PAIRS WITH EACH PAIR PERPENDICULAR TO THE TRANSECT LINE, EACH PAIR BEING A REPLICATE; C, FIVE REPLICATE SETS OF FOUR TRAPS LAID ALONG A TRANSECT LINE; D, FIVE REPLICATE SETS OF FOUR TRAPS WIDELY SPACED AT RANDOM WHEN THE HABITAT IS LARGE ENOUGH. EACH "O" REPRESENTS ONE PITFALL TRAP.



Duration of trapping

Long term monitoring programmes should be a minimum of 5 years, 2 years baseline trapping before the start of management and 3 years following management. Trapping could continue all year round, year after year or could be restricted to one or more seasons per year with the traps closed down between these trapping periods. The minimum period would be for 4 months of continuous trapping during one season, e.g. spring or summer. In New Zealand conditions there is an increase in ground-dwelling invertebrate activity during spring in particular, and this would be the season to target as a preference.

Traps need to be cleared at regular intervals and *the interval must remain as near to constant as possible throughout the monitoring study*. If the interval is too short then variation in weather may significantly affect the variation in the catch, whereas too long a period could mean seasonality of some species could influence catch variation, particularly those species which are only active as adults for a few weeks of the year. Monthly clearance or, at least fortnightly, should provide a satisfactory compromise in most habitats. If monthly clearances are chosen then the interval should be 30 days and remain constant across all months.

TRAP DESIGN

After designing the monitoring programme the next aspect is choice of pitfall trap design.

A range of pitfall trap designs are available in the literature dating from Barber (1931) to more recent times (Uetz and Unzicker 1976, Durkis and Reeves 1982, Benest 1989, Green (1996)). Long-term monitoring studies require a robust design able to withstand many clearances without altering or damaging the immediate area around the trap edge. Two suitable designs which I have used for many years are illustrated: a pipe pitfall (Figure 2) and a soft drink bottle pitfall (Figure 3). Both designs feature an outer container or sleeve that protects an inner container holding the preservative.

Pipe pitfall trap (Figure 2)

The design has been adapted from that of Moeed and Meads (1985). Various sizes of pipe could be used, but the inner container holding the preservative must fit very closely into the pipe so invertebrates cannot fit between the two surfaces. It is advisable to ensure that such a close fit exists before bulk purchase of the materials! The polyvinylchloride (PVC) pipe in Figure 2 has an internal diameter of 76 mm, which exactly equates the outer diameter of the plastic 'glass'. The pipe is approximately 160 mm long so that when sunk into the ground the 'glass' at the bottom of the trap is at least 60-70mm below the pipe lip at ground level. This means there is a considerable distance of vertical face for invertebrates to climb if they are to escape. Drainage holes 25-30 mm down from the 'glass' lip prevent the loss of invertebrates through overflow by flooding.

The trap is covered by a single piece of untreated, rough-cut 150 mm x 150 mm x 25 mm boxing timber held firmly in place by four 100 mm nails. Small wooden blocks at each corner are used as spacers to keep the cover approximately 20 mm above the ground surface. Holes should be drilled for the nails to avoid splitting. The covers should be larger than the trap entrance by at least 35-40mm to prevent rainfall, leaves and twigs falling into the trap.

Preservative in the 'glass' is a mixture of 30% monoethylene glycol ('antifreeze') solution with 70% water and a dessert spoon of common salt. Approximately 50-80 ml of this solution is adequate for monthly clearance periods. When mixing the glycol and water it is recommended that several drops of dishwashing soap solution per 2 l of preservative is added to reduce the surface tension. Reduced surface tension allows invertebrates to sink below the surface quickly.

Soft-drink bottle pitfall trap (Figure 3)

This design has been adapted from Ussher (1997) who gives directions for making up the outer container and funnel from a 2-l soft-drink bottle. The funnelling of the catch allows the inner container to be more flexible in size, provided it has a sufficiently larger opening than the base of the funnel. The trap in Figure 3 has a 110-mm diameter trap entrance, a 50-mm diameter opening at the base of the funnel and a 500-ml plastic pot with a 100-mm diameter opening as the inner container. The drain holes in the latter are 40-50 mm down from the lip.

The outer soft-drink bottle must be punctured at the base, preferably in several places, to allow any over-flow of rainwater to escape. These holes also release pressure from under the trap, which can otherwise force the whole trap out of the ground when moisture levels increase.

FIGURE 2: PIPE PITFALL TRAP WITH SECTION CUTAWAY TO SHOW PLASTIC 'GLASS' INSIDE. INTERNAL PIPE DIAMETER IS 76 MM. WOODEN COVER OFFSET TO SHOW TRAP ENTRANCE CLEARLY.

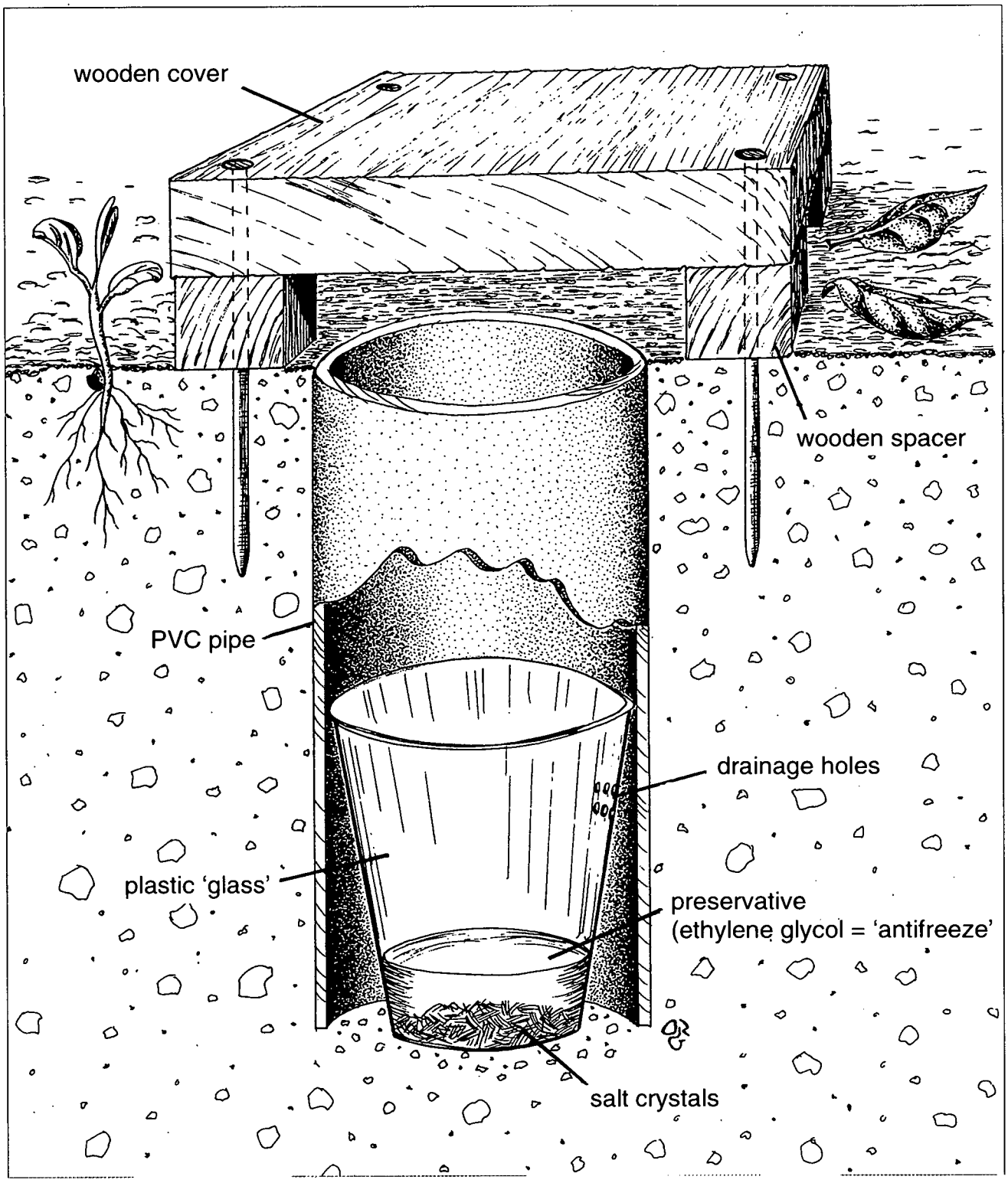
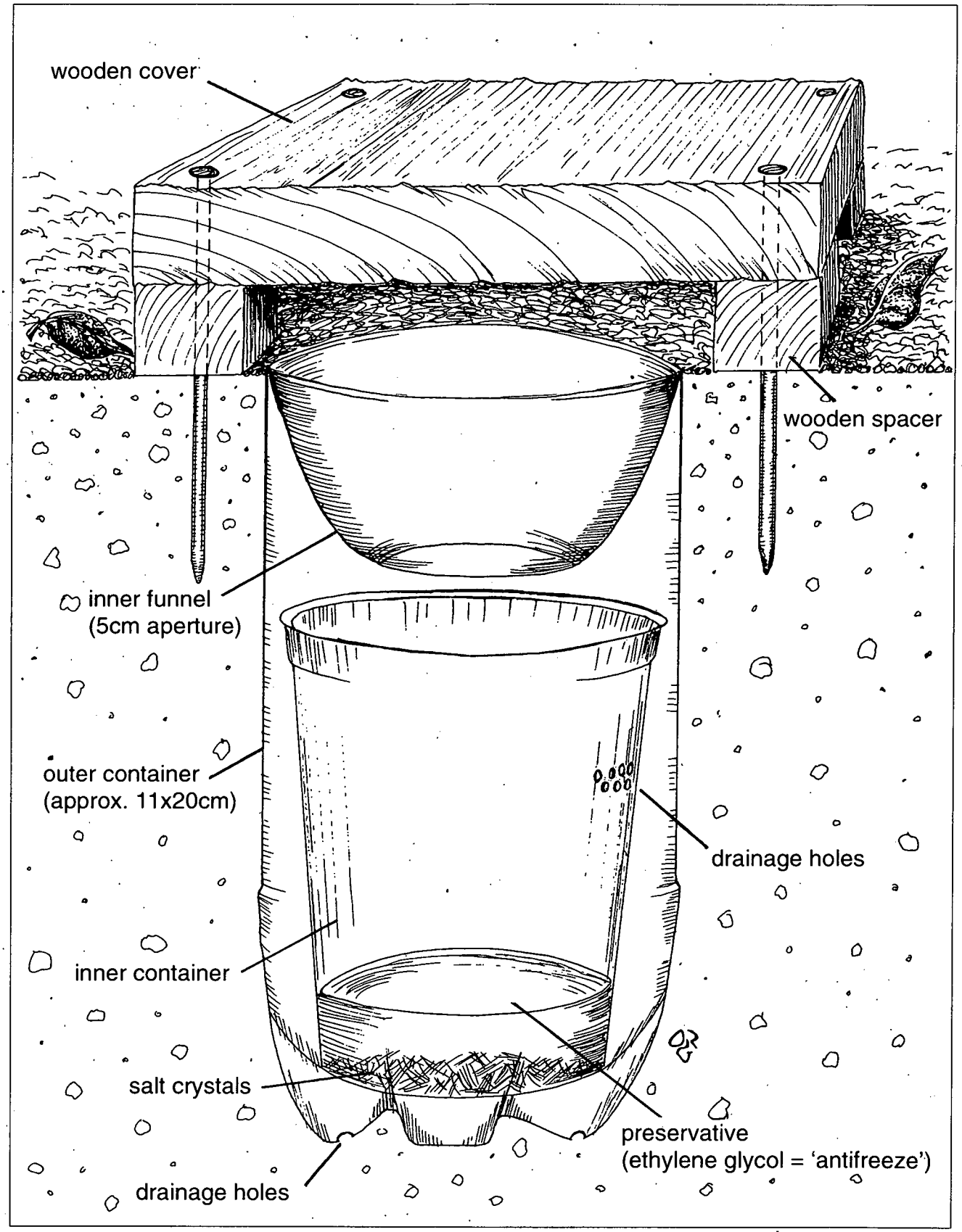


FIGURE 3: SOFT-DRINK BOTTLE PITFALL TRAP WITH FUNNEL. OUTER CONTAINER DIAMETER IS 110 MM. WOODEN COVER OFFSET TO SHOW TRAP ENTRANCE CLEARLY.



Being a larger trap than the pipe trap (Figure 2) the wooden cover needs to be larger, 200 mm x 150 mm x 25 mm is recommended. The wooden spacers and preservative solution are the same as above.

Extended clearance period modifications

There may be occasions when the interval between trap clearances is much longer than the fortnight or month recommended above, e.g. on remote offshore islands where visits may be restricted to just a few times a year. Some modifications to the trap design are recommended to prevent traps filling with litter and other debris and to ensure the preservative functions adequately for the full period. It is also advisable to use a larger capacity trap that is able to physically hold the numbers of invertebrates expected to be caught through the extended period.

Leaves and twigs can clog the trap opening or enter the trap in sufficient quantity to allow captured invertebrates to escape. This can be prevented by placing a strip of 25 mm wire mesh either around the trap opening under the cover or around the outer edge of the trap cover, tacked on, so that it covers the gap between ground and cover. The 25-mm mesh will allow invertebrates through but will hold back larger leaves and twigs.

The glycol preservative recipe can be altered to allow much longer-term trapping. The concentration of glycol is increased to 70% and mixed with a saturated solution of water and common salt. Saturated salt solution is approximately one part common salt added to three parts water. One third of the trap container should be filled with this mixture and then enough common salt crystals poured in to provide a 25-mm deep coating on the base of the trap.

These two modifications have allowed traps to remain operating satisfactorily for up to 9 months during autumn, winter and spring, on offshore islands in northern New Zealand.

SETTING UP THE TRAPS

Having chosen the trap design the next stage is to move into the field and set up the traps in one of the layouts discussed above. Having chosen the treatment and non-treatment areas where the trapping will take place it is important to check the uniformity of each trapping site prior to deciding the position of each trap and replicate of traps (see "Site variation" section above).

Trap position

Convenient access to the trap sites is important but traps should not be set on or too close to tracks. Clearly foot traffic could potentially kill the ground invertebrates which the monitoring programme aims to collect. Therefore, traps should be sited at least 5-10 m away from any tracks.

Each trap site should have firm ground around it to stand on so that during each clearance the ground will not slip and alter the nature of the surface, particularly in the immediate vicinity of the trap.

If the ground is sloping ensure the trap is not placed directly downhill from a large tree trunk because such traps can be flooded by water funnelled down the trunk from the canopy foliage above. Also avoid positioning the trap in hollows or mini-valleys which may funnel stormwater run-off. It is a good idea to place traps on

more level or gently sloping ground rather than steep slopes. Birds and heavy rain can easily dislodge the ground and litter on the lower side of the traps on steeper slopes.

Digging in traps

When digging in the traps use a trowel, or post-hole borer that is close to the size of the outer trap container or pipe to minimise damage to the ground in the immediate area around the trap lip. Some invertebrates may be temporarily attracted to the disturbance created when digging in the trap and, conversely, some are repelled (Digweed et al 1995). Therefore, while the edges remain disturbed the trap catch may be biased. For this reason, results from the first trapping period should be regarded with caution. All surplus soil should be discarded several metres away from the trap.

After digging the hole and placing the trap in the ground, pack soil tightly around the edges to hold the trap firmly in position. As the soil settles over the following months the level may need building up to maintain the ground level at the same level as the lip of the trap. For the trap to catch small- to medium-sized invertebrates down to the size of ants these levels need to be the same. If the trap edge is too high above ground it will reduce the numbers of invertebrates able to fall in. If set too low into the ground it will collect too much litter, soil and other debris which will make sorting and identification of the trap catch more time consuming. Avoid cracks and crevices between the trap edge and ground level.

Each trap should be clearly labelled and the position noted so that it can be relocated easily without the need to wander all over the site.

TRAP CLEARANCE AND MAINTENANCE

Any number of procedures can be employed when collecting the samples from the traps, but there are a number of key points to remember. Extra care is required when labelling the samples, always replace the preservative with fresh solution at each clearance, remove the used preservative from the site, leave the trap in a clean condition, ensure that the lip of the trap is flush with the ground level, replace the trap cover in exactly the same position, and avoid damage to the area around the trap.

During each trap clearance occasion the same route to each trap should be used to minimise damage to ground vegetation and litter which may be daytime hiding places for invertebrates. If the trap is on sloping ground try and approach it from the downhill side to avoid knocking litter into the trap.

Labelling

Labelling of samples is a critical aspect of trap clearance. To minimise time spent in the field labels should be pre-printed. They can be produced rapidly by laser printer, but may not always be 'fast'; i.e. the letters could fall off the paper when submerged in preservatives, such as alcohol, for long periods. A quick way to ensure this does not happen is to place the sheet of labels in a conventional oven set at 140-160° C for 60 seconds. This melts the toner into the paper fibres. Thicker paper, such as 100-gsm goatskin parchment, will also improve the durability of labels. Labels can be hand-written with pencil, but pens, such as ballpoint pens, with non-

fast inks should be avoided because the ink may dissolve in preservatives. Labels should be placed inside containers rather than taped to the outside where they could be dislodged. When placing the trap catch into the container *always double check* that it has the correct label for that trap.

Labels should contain a minimum amount of information, including locality, pitfall trap replicate number, date of trap clearance, and person responsible for clearance. Two examples of labels with sufficient information and appropriate size are:

New Zealand AK Tiritiri
Matangi I. Pitfall 1/10b
Nov 1999 C.J.Green

Auckland Region Tiritiri
Matangi I. Pitfall 1/10b
Nov 1999 C.J.Green

Trap cleanliness

Trap cleanliness is important to ensure that invertebrates are able to fall in easily. The inner sides of the trap should be clean to prevent invertebrates climbing out. Any material (particularly dead invertebrates) between the inner and outer containers of the trap that may smell as it is decomposing should be removed. Such odours could attract scavenging invertebrates and thus bias the catch of that trap. The aim of the monitoring described here is to catch samples unbiased by any attractants. The only possible exception is the presence of the solid trap cover, which may attract some invertebrate species looking for a hiding place. However, the covers should be identical on all traps used in the monitoring programme, in all replicates in both treatment and non-treatment areas thus cancelling out any bias.

Clearance procedure – an example

The following clearance procedure has proven to be quick and efficient:

- carefully remove the cover so the nail holes remain intact,
- if the trap has a funnel remove and clean with a clean cloth,
- place funnel, if the trap has one, on trap cover so it won't be forgotten,
- remove inner container with preservative and check there are no invertebrates under it, if there are collect these and add to the catch, even if alive,
- place a 120-mm square piece of fine curtain netting into a funnel which in turn is placed in the opening to a large container to remove used fluid from the site,
- pour the trap contents into the netting covered funnel and check that no invertebrates remain in the trap,
- gather the netting edges together and place in container with *correct trap label*,
- pour fresh preservative into the trap container followed by common salt crystals, ensuring that none is spilt near the trap,
- check the lip of the trap is flush with the ground, if not, add soil and litter,
- replace the container in the trap, funnel if there is one, then the trap cover using the same nail holes in the ground.

An alternative to using pieces of curtain netting is to carry a fine, tea-strainer type sieve, which is placed in the funnel instead, the sample poured in, then the invertebrates can be flushed from the inverted sieve, through the funnel, into the labelled container with a wash-bottle of preservative. This does entail carrying another container of fluid, in addition to one carrying fresh glycol and one for the used glycol.

The amount of preservative required in each trap may vary with season and between traps at each site. During periods when increased rainfall is expected the traps should be stocked with more salt crystals, say a tablespoon, or a greater volume of glycol say double the 50 ml recommended in the "Pipe pitfall trap" section above.. There may be some individual traps that have a history of flooding so these should be routinely refilled with slightly more preservative.
After returning from the field fresh 30% glycol preservative should be added to each trap sample sufficient to cover and keep the invertebrates in good condition until they are sorted and identified.

SORTING AND IDENTIFICATION

Which species to identify

The degree to which samples are sorted and identified depends on the aims of the monitoring programme. In general, it is virtually impossible to identify all specimens to a species level because so many are yet to be formally described by taxonomists. Some invertebrate groups are better known and described than others, and these could be the focus for identification to species or genus level. For others, family or even order level identification may be sufficient to show population changes.
Therefore, it is appropriate to sort and identify samples to at least some broad grouping such as order or family level and perhaps focus on certain species within these, such as indicator species or groups of species. For example, wetas, especially ground and cave weta species, spiders, or an entire family of beetles such as Carabidae, could be the focus of recording. At present there is still much to learn about which groups of invertebrates may be good indicators of the effects of changed management such as pest control. However, it is advisable to include some broad measure of most ground invertebrate groups. Examples of two recording sheets, one for broad invertebrate groups, and one that focuses on one group, the spiders, are provided in Appendix 1 and 2. Setting up a reference collection of identified specimens is always useful in speeding up identifications.
Counts of species groups or species will give both qualitative and quantitative information on the changes in invertebrate populations. If broad species groups are used then some further measurement of size or biomass of the catch is recommended. This could be particularly important in monitoring programmes relating to predator control. This could involve measuring the size of all invertebrates above a certain threshold and recording within size classes, as in Appendix 1 and 2, or recording the biomass of each component group or of the whole sample from each trap.
Size class thresholds may vary between groups depending on the aims of the monitoring programme. Three or 5 mm were chosen as the lower thresholds in the study illustrated in Appendix 1, i.e. all invertebrates below these measurements were ignored. Biomass measurements are taken by drying the catch to a uniform level then weighing. However, this may destroy some soft-bodied species and make later identification difficult or impossible. All soil and litter must be removed before weighing.

Equipment for sorting and identification

It is important to allow adequate time and resources for sorting and identification. Access to a binocular microscope is an absolute necessity, together with various instruments such as tweezers, wash bottles, 75% ethanol (ethyl alcohol) for long-term storage, vials or containers with a good seal for storage. Facilities to rinse the samples in water and transparent dishes for viewing under the microscope are needed. Taxonomists in other institutions may need to be consulted for identifications and this needs to be allowed for in both time and financial budgets.

Sorting procedure

The following sorting procedure has proven to be quick and efficient:

- pour the sample into a large container of water to rinse thoroughly,
- retain the label but remove the netting and any large leaves or twigs, ensuring that no invertebrates remain on them,
- netting and sample containers can be temporarily stored in a bucket of dilute bleach solution and washed for subsequent reuse,
- pour off the excess water then pour sample into clear dish for viewing under the microscope,
- individual invertebrates can be measured using an ocular micrometer or a stage-mounted ruler, made from several cut sections of a plastic ruler joined together and placed under the viewing dish. Many invertebrates swell up when in fluid for long periods and this needs to be allowed for when taking measurements,
- record identification and size class,
- discard any large, commonly caught, easily identified species, such as ground weta, large spiders, and possibly large beetles, to reduce the volume of the sample for long-term storage,
- place label and remainder of sample in vial, top up with 75% ethanol and seal,
- store vials in cool, dark place, preferably with an even temperature.

Sample storage and disposal

All samples should retain individual labels and be kept separate and not bulked. In general, samples should be retained in storage until the monitoring programme has ended and all analysis is complete. Unless all species are identified from the beginning of the study, it is quite possible that some early samples may need to be resorted after it becomes apparent which species have increased or decreased in numbers over time.

After completion of the study the samples should be made available to institutions that hold invertebrate collections, such as museums or the New Zealand Arthropod Collection held by Landcare Research Ltd. These institutions may agree to hold the material during the course of the study and may agree to provide suitable containers to hold the samples.

RECORDING FIELD INFORMATION

Weather recordings

Weather can have a significant influence on activity patterns and behaviour of invertebrates in the short term. For example, a cold spell of a few days will reduce the numbers of some species emerging to feed, and conversely greater numbers can be observed during warmer, humid, calm nights. Weather can also affect

populations over a longer term such as throughout a season or longer. For example, drought can lead to significant declines of some invertebrate groups that may take some years to recover. In contrast, warmer than usual winters could lead to higher numbers of some species during the following spring or summer. Long-term monitoring should identify such changes in numbers, but monitoring must continue long enough to be certain that the observed effects on the invertebrate populations are due to the treatment rather than factors such as the weather.

It is for this reason that weather recordings must be taken in the vicinity of the trapping sites, particularly rainfall, and maximum and minimum temperatures on a daily basis. Such recordings could be crucial to explaining variation during some seasons that may be inconsistent with expected changes owing to the treatment.

Field notes

At the start of the monitoring study detailed descriptions of the habitat at each site in both treatment and non-treatment areas should be recorded. At the end of the monitoring programme these descriptions should be reviewed to ensure they are still valid, with any changes noted. Photographic records from set photo points can also be extremely useful in recording site characteristics.

During each trap clearance occasion any short-term changes in habitat, such a fallen tree near a trap, mushroom growing beside the trap, spider web over the trap entrance, etc should be noted as these may help to explain short-term changes in the invertebrates captured.

DISCUSSION

Pitfall traps are essentially a measure of invertebrate activity. The aim is for the trap to catch those individuals that would naturally cross the ground area where the trap entrance is located. Traps set for long-term monitoring studies are not generally designed to attract invertebrates, because this would bias the catch. However, other studies, particularly surveys, may employ attractants in the trap to draw in particular species over a short time and in specialised habitats, such as caves (Barber 1931).

Pitfall traps have many advantages as a monitoring method. They can systematically catch a wide variety of invertebrates, are cheap to make, easy to set up and maintain, cause little damage to habitats, and can be left unattended for long periods yet still deliver invertebrates in good condition for identification.

Disadvantages include susceptibility to flooding, requirement for a reasonably high number of replicates to account for both variable behaviour of invertebrates and large variability in micro-site and macro-site conditions within habitat types. For long-term studies the sampling is destructive, i.e. the invertebrates are generally killed at the time of collection.

Most of these disadvantages can be minimised or allowed for in the design of the programme. In particular it is important to stress that pitfall trapping is generally not a suitable method to determine absolute population density of a species in an area without a second method to calibrate the data collected (Topping and Sunderland 1992, Anderson 1995)

Both pitfall trap designs illustrated above have advantages and disadvantages. The pipe pitfall trap design has several advantages over the soft-drink bottle design.

Without a funnel it is less likely to get clogged with litter and the inside of the pipe tends to be self-cleaning when the 'glass' is pulled out during clearance. However, without a funnel it is possible for invertebrates to escape, if they can walk up a vertical surface. The smaller trap opening may also allow larger invertebrates, e.g. large spiders and weta to avoid capture by virtually walking over the trap, although behavioural responses to traps varies between species (Topping 1993).

The larger soft-drink bottle trap will potentially catch greater numbers of invertebrates, particularly larger species, compared to the pipe trap. Another advantage is that the funnel should prevent the escape of virtually all captured invertebrates, even those few that escape the inner container. The latter are restricted to the odd large spider or flatworm. However, the funnel gets dirty easily and needs to be cleaned on each clearance occasion.

Between the two designs the pipe trap is the more robust, is easier to service and thus is recommended above the soft-drink bottle design.

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APPENDIX 1. AN EXAMPLE OF A RECORDING SHEET THAT FOCUSES ON THE GENERAL INVERTEBRATE GROUPS.

Species (mm)	1/1a	1b	2a	2b	3a	3b	4a	4b	5a	5b	6a	6b	7a	7b	8a	8b	9a	9b	10a	10b	**Total**
Worms (-15+)																					0
Slugs (5+)																					0
Flatworms (15+)																					0
Spider - v lg (15+)																					0
" - lg (10-15)																					0
" - med (5-10)																					0
" - sm (3-5)																					0
Opilion - med (5-10)																					0
" - sm (3-5)																					0
Isopoda - lg (10-15)																					0
" - med (5-10)																					0
Amphipd-lg (10-15)																					0
" - med (5-10)																					0
Total	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**0**
Archaeog-lg (10-15)																					0
" - med (5-10)																					0
Blattodea-lg (10-15)																					0
" - med (5-10)																					0
" - sm (3-5)																					0
Grd wta - v lg (15+)																					0
" - lg (10-15)																					0
" - med (5-10)																					0
" - sm (3-5)																					0
Cav weta lg (10-15)																					0
" - med (5-10)																					0
" - sm (3-5)																					0
Tree weta (-15+)																					0
Other spp (-15+)																					0
Total weta	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**0**
Hemipter-lg (10-15)																					0
" - med (5-10)																					0
Odontr ad (10-15)																					0
Coleopter-vlg (15+)																					0

" - lg (10-15)																					0
" - med (5-10)																					0
" - sm (3-5)																					0
Calliphorid flies																					0
Tipulidae-lg (10-15)																					0
" - med (5-10)																					0
Lepidopt-lg (10-15)																					0
" - med (5-10)																					0
Hymenop-lg (10-15)																					0
" - med (5-10)																					0
Total Insects	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**0**
Millipede-v lg (15+)																					0
" - lg (10-15)																					0
" - med (5-10)																					0
Centiped-v lg (15+)																					0
" - lg (10-15)																					0
" - med (5-10)																					0
Total	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**0**
Total Inverts	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**0**
Total v lg 15+ mm	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**0**
" v lg (15+)+(-15+)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**0**
lg 10-15 mm pt	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total lg 10-15 mm	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**0**
Total v lg + lg	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**0**
med 5-10 mm pt	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Tot med 5-10 mm	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**0**
Tot v lg + lg + med	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**0**
Notes																					

APPENDIX 2. AN EXAMPLE OF A RECORDING SHEET THAT FOCUSES ON ONE INVERTEBRATE GROUP, THE SPIDERS.

Species (mm)	1/1a	1b	2a	2b	3a	3b	4a	4b	5a	5b	6a	6b	7a	7b	8a	8b	9a	9b	10a	10b	Tot	Tot
M. spA ad F vlg																					0	
" ad M vlg																					0	
" imm vlg																					0	
" imm lg																					0	
" imm med																					0	
" imm sm																					0	
" imm v sm																					0	0
M. spB ad F lg																					0	
" ad F med																					0	
" ad M med																					0	
" imm med																					0	
" imm sm																					0	
" imm v sm																					0	0
Amphinect ad F lg																					0	
" ad F med																					0	
" ad M med																					0	
" imm med																					0	
" imm sm																					0	
" imm v sm																					0	0
Aparua ad F lg																					0	
" ad M lg																					0	
" ad F med																					0	
" ad M med																					0	
" imm med																					0	
" imm sm																					0	0
Hypodrass ad F lg																					0	
" ad M lg																					0	
" ad F med																					0	
" ad M med																					0	
" imm med																					0	
" imm sm																					0	
" imm v sm																					0	0
Salticid ad F med																					0	

" ad M med																					0	
" ad F sm																					0	
" ad M sm																					0	
" imm sm																					0	
" imm v sm																					0	0
Aorangia ad F sm																					0	
" ad M sm																					0	
" imm sm																					0	
" imm v sm																					0	0
Reinga ad F med																					0	
" ad M med																					0	
" imm med																					0	
" imm sm																					0	0
Theridiid ad F med																					0	
" ad F sm																					0	
" ad M sm																					0	
" imm sm																					0	
" imm v sm																					0	0
Pahoroid sm																					0	
" v sm																					0	0
Hahniid v sm																					0	0
Lycosa med																					0	
" sm																					0	0
Dolomedes lg																					0	
" med																					0	0
Sidymella med																					0	0
Spider indet med																					0	0
Spider indet sm																					0	0
Spider indet v sm																					0	0
Total v sm	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
Total Spiders	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

What use are dead tree ferns?

Colin Ogle[1], Graeme La Cock[1] and Bob Halsey[1]

[1]Department of Conservation, Private Bag 3016, Wanganui

Bob Halsey died tragically in 1998. We would like to acknowledge Bob's contribution to the writing of this paper and the work he did for the Department of Conservation.

ABSTRACT

As a result of an application to the Department of Conservation (DOC) to take the trunks of dead tree ferns from a scenic reserve near Wanganui, we devised a survey method to assess the status and roles of dead tree ferns in the reserve. Thirty-nine dead standing tree fern trunks were found, comprising 28 ponga (*Cyathea dealbata*) and 11 mamaku (*C. medullaris*). Of these, 12 were judged as being sufficiently solid to hold together, should they be felled and removed. Twenty-one species of epiphytes and vines were found on dead trunks of tree ferns, with an average of 2.3 species per trunk. Hollow trunks of fallen tree ferns provided different microhabitats from dead standing trunks. Felling and removal of dead tree ferns would have caused considerable damage to other trees, living tree ferns, and shrubs and the loss of microhabitats in the forest. We concluded that no dead tree fern trunks should be taken from the reserve.

INTRODUCTION

Tree ferns (Families Cyatheaceae, Dicksoniaceae) (Brownsey & Smith-Dodsworth 1989) are prominent in many New Zealand forests, including seral forest and scrub (Wardle 1991). Climatic factors influence the distribution of mainland species (Wardle 1991) but in lowland forest of the North Island as many as seven species may occur together. Tree ferns that establish in well-lit situations, such as canopy gaps and seral vegetation, tend to die as heavy shade develops, but their trunks remain standing for some years. Tree fern trunks have an economic value, being used in horticulture and landscaping for fences, retaining walls, supports for vines and epiphytes and, when shredded, as a base for potting mixes. Wheki (*Dicksonia squarrosa*) are the most widely used tree ferns for making fences, being relatively light, durable, and widely available. Mamaku (*Cyathea medullaris*) trunks are sometimes preferred because they are also durable and grow taller than wheki, but they are more bulky and heavy. Ponga (*C. dealbata*) are not commonly used because the trunks are not durable. Legal commercial harvesting occurs on private lands and in exotic forests.

In 1998, DOC received an application from a local marae to take "dead ponga trunks" from Ngawaierua Scenic Reserve (SR) near Wanganui, for the purpose of making a fence. Because the application was not specific as to whether the term "ponga" meant *C. dealbata* only, or whether it had been used idiomatically to mean any tree fern, we included all tree ferns in our study.

A list of plants made in Ngawaierua SR in 1968 (Ogle 1998) included the tree ferns ponga, mamaku, and wheki. The reserve is lowland forest dominated by tawa (*Beilschmiedia tawa*), and adjoins SH3 between Kai-iwi and Maxwell, west of Wanganui. In 1998, no dead tree ferns could be seen from the highway, but live mamaku were a prominent landscape feature of the reserve. Of concern to the department were the possible impacts of removing tree fern trunks from the small reserve (3.5 ha) and a lack of information on the roles that these trunks might have in the reserve's ecology. Therefore, as part of the consent process, we surveyed the reserve for dead and living tree ferns to assess their abundance, distribution, condition, and relationships with other inhabitants.

METHODS

The tree fern survey

We surveyed the whole reserve on 15 January 1998. The identity of each dead standing tree fern was determined, its diameter at breast height (dbh) and 'usable' height measured, and a qualitative assessment was made of its condition, i.e. its degree of decay. A height of 1.5 m was taken as the minimum length for use in fencing. The distance to the nearest neighbouring tree fern was measured. Records were made of the species and abundance of epiphytes and vines on each dead tree fern. Mosses and lichens were noted on several trunks, but were not surveyed consistently. Similar records were made from a sample of 4 living tree ferns, being the nearest live specimens to each of the first 4 dead ferns encountered. The survey took about 9 person-hours.

Several dead, fallen trunks of tree ferns were examined and one was split open. Brief notes were made on the associated vascular plants and the invertebrates found on and within the hollow trunks.

RESULTS

Abundance, distribution and quality of dead standing tree ferns

The survey revealed 39 dead standing tree fern trunks that were >1.5 m tall (Table 1), or about 11 dead trunks per ha. Many of the 39 trunks were remote from all other dead trunks (Table 1) and they tended to be near the top edge of the reserve, which is the most remote area from the road. A stream separates the forest from the road, which would have added to the difficulties of removing tree fern trunks. The dead standing tree ferns comprised 28 ponga and 11 mamaku (Table 1). All live tree ferns encountered were of the same two species, apart from one katote (soft tree fern, *C. smithii*). Unusually, for lowland forest in this district, we found no specimens of wheki, dead or living, although the species had been recorded here in 1968 (Ogle 1998).

Eight of the 39 dead tree ferns were assessed as being "rotten", meaning that they would fall apart if an attempt were made to move them (Table 1). Nineteen were classed as "semi-rotten", meaning that even if they could be removed intact, they would have minimal useful life thereafter. In other words, about 70% of the standing dead tree ferns would be useless for the stated purpose of removing them.

The remaining 12 trunks, of which eight were mamaku, were assessed as being "sound" or "solid" (Table 1).

The numbers of epiphytes and vines

The species and abundance of epiphytes and vines associated with the 39 dead and 4 live tree ferns are shown in Table 1. The data are resorted in Table 2 to show the distribution and abundance of each epiphyte and vine species on the same tree ferns. Because mosses and liverworts were not recorded consistently, they are not considered further in this analysis. Also omitted from further analysis is a single plant of Scotch thistle (*Cirsium vulgare*) on a ponga. Twenty-one native vascular plant species were found as epiphytes and vines on the 39 dead standing trunks. These comprised nine fern species, six shrub or tree species, a perching "lily" and five species of woody (angiosperm) vines (Table 1).

Only some species of epiphytes had a tufted growth form that allowed individual plants to be counted. Vines, i.e. climbing ferns and woody vines, could not be counted individually and were assessed instead by assigning them an abundance category, which is a qualitative measure of plant cover on each trunk (Table 1).

Five trunks had no epiphytes, of which 4 were ponga and 1 a mamaku; all were recorded as being 'rotten' or 'semi-rotten'. The remainder had between 1 and 4 species of native epiphytes and vines, except for 2 trunks with 5 species. The average number of epiphyte and vine species was 2.3 species per dead tree fern.

On the small sample of 4 living tree ferns, up to 4 species of epiphyte and vine were found, with an average of 2.5 species per tree fern. Although the sample of live tree ferns is too small to produce statistically significant results, it appears that living tree ferns have a similar variety of epiphytes and vines to dead tree ferns. One live ponga had the only specimen seen in the reserve of the fern relative, *Tmesipteris elongata*.

ABUNDANCE OF EPIPHYTES

Individual plants could be recognised of 13 species of epiphyte (Table 1). For these 13 species, at least 83 individual plants occurred across the 39 dead trunks, a mean of just over 2 epiphytes per trunk. Seven dead trunks had 5 or more individuals of these 13 species on them. Eight trunks without epiphytes had climbing ferns and/or woody vines; 18 trunks (46%) had both epiphytes and vines.

Only 8 dead tree ferns were assessed as being feasible for removal, namely the mamaku specimens identified as "sound" or "solid" in Table 1. All supported vines and epiphytes, and some had amongst the highest numbers of individuals and species. If any of these were to be felled, not only would the attached plants die, but there would be considerable peripheral damage. Surrounding trees, living tree ferns, shrubs, and ground cover plants would be broken or crushed by the falling tree fern trunks and during the carrying of trunks from the reserve.

We made some casual observations of tree fern trunks that had already fallen in the reserve. A hollow trunk that we split open contained the roots of forest trees and shrubs, and it was inhabited by invertebrates, including insects, spiders, millipedes, minute land snails, isopods and amphipods. Although we did not make systematic records, we noted that seedlings and young ferns had established on fallen tree fern trunks.

DISCUSSION

At Ngawaierua Scenic Reserve there is vigorous regeneration of tree ferns on some forest margins, and stands of tall mamaku grow along gullies under the forest canopy. Travellers on State Highway 3 have clear views of the crowns of these tree ferns against the forest. The presence of dead tree ferns in the reserve, including large numbers decaying on the forest floor, suggests that the majority of tree ferns established some decades ago. Apart from around the margins or in gaps, fewer live tree ferns are likely to occur here in the future.

Tree ferns of one or more species are a distinctive landscape feature of much New Zealand rain forest, especially in the lowlands. The distribution of tree fern species is limited by frost and drought, more for some species than others. Ponga, mamaku and wheki appear early in forest succession after catastrophic events such as fire and land-slides. They are most abundant on river terraces, in gullies and other moist places, but regenerate also in canopy gaps and under a forest canopy where there is little understorey, including planted exotic forests.

Living tree ferns affect the forest and other forest inhabitants in various ways. In early succession, they provide shade and litter for plants to grow below them, and their dense, matted, wiry root systems hold soil together. Often there are few other plants growing under larger tree ferns because tree fern roots compete strongly for water, the crowns generate heavy shade (Dawson 1988) and the fall of dead fronds smothers other plants.

Epiphytes grow on both living and dead tree ferns (pers. obs.; Dawson 1988; Dawson & Lucas 1993). Native vines use the tree ferns as a climbing route from the forest floor to the canopy (Dawson 1988), and it may be that a dead tree fern is a clearer route to the canopy than a live tree fern. Our sample of live tree ferns was too small to conclude that there are significant differences between dead and living trunks with respect to either the abundance or the range of epiphytes and vines.

Fallen tree ferns are frequently the places where seedling forest trees establish. The hollow interior of a fallen trunk is a source of moisture for other plants. Although we did not undertake quantitative work on invertebrates, we found that the fibrous outer coat and the hollow inside of one tree fern trunk contained native invertebrates. These animals are an integral part of the forest ecosystem and the biodiversity of the reserve.

CONCLUSIONS

Our survey showed that dead tree ferns were an integral part of the forest ecology in Ngawaierua Scenic Reserve. They were there in low numbers only, and supplied microhabitats for other species of native flora and fauna. Their removal would have caused unacceptable damage to the small area of forest. As a result, we concluded that there should be no harvesting of dead tree fern trunks from Ngawaierua Scenic Reserve. In passing, we noted that there were numerous dead tree ferns on private land immediately east of the reserve. They were standing in rough pasture from which their removal would have been both easier and less damaging ecologically than taking them from the adjoining reserve.

Our survey methodology and findings should be applicable to other forests where tree fern removal is an issue. However, we suggest that a larger sample of living tree ferns be included in future surveys, particularly if removal of living tree ferns is involved. It is possible that some epiphytes and vines occur in disproportionately higher numbers on dead tree ferns than living tree ferns, or even other tree species. Our survey method could be adapted quite readily to test this hypothesis.

TABLE 1: TREE FERNS IN NGAWAIERUA SCENIC RESERVE

TREE FERN SPECIES[1]	HEIGHT (m)	D.B.H (cm)	DISTANCE TO NEAREST TREE FERN NEIGHBOUR (m)	VINES & EPIPHYTES (SPECIES AND ABUNDANCE)[2]	NOTES (e.g. soundness of the trunk; accessibility and likely damage to surrounds, if removed)
Dead tree ferns					
Ponga	2.5	18	10.0	Asp. fla.(5); Asp.pol.(2); Mel.ram.(1)	Semi-rotten. Near top of slope
Ponga	2.0	20	0.2	Mic.sca. (o); Asp.gra. (1)	Rotten - base coalesced with that of a live treefern.
Ponga	2.0	18	3.0	Asp.fla.(3); Met.ful.(a)	Rotten
Mamaku	2.0	20	3.0	Mic.sca.(o); Met.ful.(u)	Rotten - base coalesced with that of a live treefern.
Ponga	4.0	20	3.0	Asp.fla.(3); Ble.fil.(o); Asp.gra.(1);Mic.sca.(u)	Rotten
Mamaku	3.5	20	0.5	Asp.fla.(1); mosses (o)	Solid
Ponga	3.5	20	0.5	0	Rotten
Ponga	2.5	16	20.0	0	Semi-rotten
Ponga	4.0	19	12.0	Asp.obl.(1);Asp.pol.(1);Cir.vul.(1); Asp.fla.(1); Asp.gra.(1)	Semi-rotten
Ponga	4.5	19	12.0	Met.dif.(c); Asp.gra.(1); Mic.sca.(c,on base); Asp.fla.(1)	Semi-rotten
Ponga	3.0	23	15	Asp.obl.; Pse.cra.(1); Asp.pol.(1)	Semi-rotten
Mamaku	3.5	20	20.0	0	Semi-rotten
Mamaku	7.0	24	7.0	Rip.sca.(twining to 1/2 way);Asp.gra.(1); Asp.fla.(2); lichens (o)	Sound; at top of densely veg. slope
Mamaku	8.0	21	7.0	Met.ful.(o; flowering age at top); Met.per.(c); Asp.fla.(c); Wei.rac.(1)	Sound; at top of densly veg. ridge, among dense vines
Mamaku	10.0	26	15.0	Pyr.ele.(o); Mic.sca.(u); Met.per.(u); Asp.fla.(3); Gen.rup.(1); mosses (o)	Splitting length-wise
Ponga	6.0	18	3.0	0	Top 4m in full sun; semi-rotten
Ponga	6.0	19	3.0	Bra.rep. (1)	Top 4m in full sun; semi-rotten
Ponga	3.0	25	50 +	Met.per.(c)	Semi-rotten
Mamaku	3.0	18	50 +	Pte.mac.(1);Mic.sca.(o); Mac.exc.(1)	Sound; top metre curved; remote site
Mamaku	6.0	18	50 +	Mic.sca.(o - fertile); Asp.fla.(5 -fertile); Met.per.(o)	Sound
Ponga	5.0	12	50 +	Asp.fla.(1)	Semi-rotten, wobbly
Ponga	3.5	18	50 +	Rip.sca.(climbing to top); Mic.sca,(o)	Semi-rotten
Ponga	2.0	16	20.0	Asp.obl.(1); Mic.sca.(o); Col.has.(1); Met.dif.(climbing to top)	Semi-rotten
Ponga	2.5	16	50 +	Asp.fla.(1); Mic.sca.(u); Met.dif.(climbing to1/2 way)	Semi-rotten

[1] *Ponga = Cyathea dealbata; mamaku = C. medullaris.*

[2] *Abundance by actual counts or by an abundance rating for that treefern trunk (u = uncommon; o = occasional; c = common; a= abundant).*

[3] *Plant names are listed in full in Table 1A.*

TABLE 1: TREE FERNS IN NGAWAIERUA SCENIC RESERVE cont.

TREE FERN SPECIES[1]	HEIGHT (m)	D.B.H (cm)	DISTANCE TO NEAREST TREE FERN NEIGHBOUR (m)	VINES & EPIPHYTES (SPECIES AND ABUNDANCE)[2]	NOTES (e.g. soundness of the trunk; accessibility and likely damage to surrounds, if removed)
Dead tree ferns cont.					
Ponga	2.0	21	8.0	0	Semi-rotten
Ponga	6.0	15	8.0	Mic.sca.(o); Rip.sca. (climbing to top)	Semi-rotten
Ponga	3.0	15	50 +	Met.per.(o); Mic.sca.(o)	Semi-rotten
Ponga	6.0	24	3.0	Asp.fla.(10); Ble.fil.(o); Par.het.(climbing to 1/2 way); Met.ful.(climbimg to top)	Sound; up ridge & surrounded by dense vines and shrubs
Ponga	10.0	19	3.0	Asp.obl.(1); Met.dif.(o)	Sound; top 3 m bent
Mamaku	10.0	21	30.0	Mic.sca.(u)	Sound; top 1/2 in sun, bent 3 m from top; top of reserve
Mamaku	6.0	14	50 +	Asp.obl.(1); moss (u)	Sound
Ponga	2.0	18	20.0	Asp.obl.(1); Met.per. (climbimg to top)	Semi-rotten
Ponga	3.0	19	5.0	Mic.sca.(u)	Semi-rotten
Ponga	2.5	18	5.0	Ble.fil (u); Mac.exc.(1); Asp.obl.(2); mosses (o)	Semi-rotten
Ponga	2.5	24	20.0	Asp.fla.(4); Asp.pol.(1)	Rotten
Ponga	2.5	24	20.0	Asp.obl.(1); Mic.sca.(c); Met.per.(o); Asp.fla.(1); Met.dif.(climbimg to top)	Rotten
Ponga	2.0	20	20.0	Mic.sca.(c)	Solid
Ponga	2.0	24	20.0	Mic.pus.(c); Asp.fla.(6)	Sound
Mamaku	10.0	24	50 +	Asp.gra.(1); Gen.rup.(4); Met.ful.(c); Met.per.(c); Mic.sca.(c)	Sound; bent near top
11 mamaku; 28 ponga					
Live tree ferns					
Ponga	3.5	18		Mic.sca.(o); Asp.pol(7)	
Ponga	4.0	20		Wei.rac.(1)	
Ponga	4.0	21		Tme.elo.(2); Asp.fla.(1); Met.dif.(o); Mic.sca. (o)	
Mamaku	4.0	20	3.0	Met.ful.(u);Mic.pus.(u); Pyr.ele.(o)	

[1] *Ponga = Cyathea dealbata; mamaku = C. medullaris.*

[2] *Abundance by actual counts or by an abundance rating for that treefern trunk (u = uncommon; o = occasional; c = common; a= abundant).*

[3] *Plant names are listed in full in Table 1A.*

TABLE 1A: ABBREVIATIONS OF SPECIES' NAMES

ABBREVIATION	FORMAL NAME	COMMON NAME(S)
Ferns and fern allies		
Asp.fla.	*Asplenium flaccidum*	hanging spleenwort
Asp.gra.	*Asplenium gracillimum*	slender hen and chicken fern
Asp.obl.	*Asplenium oblongifolium*	shining spleenwort
Asp.pol.	*Asplenium polyodon*	sickle spleenwort
Ble.fil.	*Blechnum filiforme*	climbing blechnum
Mic.pus.	*Microsorum pustulatum*	hound's tongue fern
Mic.sca.	*Microsorum scandens*	
Pte.mac.	*Pteris macilenta*	brake
Pyr.ele.	*Pyrrosia eleagnifolia*	leather-leaf fern
Tme.elo.	*Tmesipteris elongata*	tmesipteris
Trees and Shrubs		
Bra.rep.	*Brachyglottis repanda*	rangiora
Gen.rup.	*Geniostoma rupestre* ssp. *ligustrifolium*	hangehange, NZ privet
Mac.exc.	*Macropiper excelsum*	kawakawa
Mel.ram.	*Melicytus ramiflorus*	mahoe, whitey-wood
Pse.car.	*Pseudopanax crassifolius*	horoeka, lancewood
Wei.rac.	*Weinmannia racemosa*	kamahi
Lianes (Vines)		
Met.dif.	*Metrosideros diffusa*	aka, white rata vine
Met.ful.	*Metrosideros fulgens*	scarlet rata vine
Met.per.	*Metrosideros perforata*	aka, white rata vine
Par.het.	*Parsonsia heterophylla*	NZ jasmine
Rip.sca.	*Ripogonum scandens*	supplejack
Herbaceous plants		
Cir.vul.	*Cirsium vulgare*	Scotch thistle (exotic species)
Col.has.	*Collospermum hastatum*	perching lily

TABLE 2. DISTRIBUTION OF EPIPHYTES AND VINES ON TREE FERN TRUNKS, NGAWAIERUA SCENIC RESERVE

SPECIES OF EPIPHYTE/VINE	NO. OF DEAD TRUNKS (N=39) WITH THE SPECIES	TOTAL NO. OF EPIPHYTES ON DEAD TRUNKS[1]	NO. OF LIVE TRUNKS (N=4) WITH THE SPECIES	TOTAL NO. OF EPIPHYTES ON LIVE TRUNKS[1]
Tufted ferns and fern allies				
Asplenium flaccidum	16	44+	1	1
Asplenium gracillimum	6	6		
Asplenium oblongifolium	8	9		
Asplenium polyodon	4	5	1	7
Pteris macilenta	1	1		
Tmesipteris elongata			1	2
Climbing ferns				
Blechnum filiforme	3			
Microsorum pustulatum	1		1	
Microsorum scandens	17		2	
Pyrrosia eleagnifolia	1		1	
Shrubs				
Brachyglottis repanda	1	1		
Geniostoma rupestre	2	5		
Macropiper excelsum	2	2		
Melicytus ramiflorus	1	1		
Pseudopanax crassifolius	1	1		
Weinmannia racemosa			1	1
Woody vines				
Metrosideros diffusa	6		1	
Metrosideros fulgens	5		1	
Metrosideros perforata	7			
Parsonsia heterophylla	1			
Ripogonum scandens	3			
Angiosperm herbs				
Cirsium vulgare	1	1		
Collospermum hastatum	1	1		
Others				
Lichens	1			
Mosses	4			

[1] *Note that climbing ferns and woody vines are excluded from these columns, because individuals could not be distinguished for counting.*

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