An Integrated Design Methodology for Inventing Humane Animal Traps in Accordance with NAWAC guidelines

---

A thesis
submitted in partial fulfilment
of the requirements for the Degree of
Doctor of Philosophy

at
Lincoln University
by
Ian R. Domigan

Lincoln University
2011

Abstract of a thesis submitted in partial fulfilment of the requirements for the Degree of Doctor of Philosophy.

An Integrated Design Methodology for Inventing Humane Animal Traps In Accordance with NAWAC guidelines

by

Ian R. Domigan

New Zealand's fauna are depredated upon by introduced mammals and human intervention is required either in the form of poisoning or trapping to protect many native species. In 1999, New Zealand introduced the Animal Welfare Act which spawned the National Animal Welfare Act Committee (NAWAC) guidelines, which then set performance standards for animal traps. The major traps used failed to meet these standards because of time to kill (kill traps) or degree of trauma (restraint traps) to target parts. Consequently, new traps need to be developed that have a higher humaneness level to satisfy the NAWAC guidelines.

There are two aims to this thesis. The first aim is, to develop an inventive methodology that guides inventors in developing animal kill traps to meet the Class A/B criteria of the NAWAC guidelines. The inventive methodology presented is a blend of Action Research, mechanical design, ecology and human psychology and is demonstrated by the invention of animal traps. The animal traps invented are then classified according to the NAWAC guidelines for possum (class B), ferret (class A), rat (class A) and stoat (class A). Later in the thesis the inventive methodology is modified to incorporate the "natural keys". This modified methodology shows the primary concern is the trigger development and then designing the means of delivering the lethal blow as a secondary item. A simple rat trap is designed to demonstrate this principle.

The second aim is, to develop a methodology to holistically compare one trap against another. This holistic comparison is called the "Trap Factor". The Trap Factor equation is presented, which allows a number of traps to be compared on a number of attributes, namely:

humaneness, ease of use, efficiency, trap placement and annual cost of the traps being compared. The Trap Factor is demonstrated on the traps invented in this thesis and used on data from other researchers which can result in conclusions that are dramatically opposed to those the researchers themselves may have drawn from their data when the other trap factor variables are considered rather than solely efficiency. The Trap Factor is further applied to compare two different trapping systems (snare and padded leg-hold) and from the literature indicates that the snare can be a humane killing system. The Trap Factor then identifies the focus area of ease of use as an area where improvement could be made.

There were five (Blitz, Bulldog (later called Warrior), Hammer, Thumper and Dominus) commercial traps developed and three concept traps developed to target ferrets, multi-species and rats. The Blitz trap was designed as an easier trap to set than the Bulldog and is currently sold only in New Zealand. The Bulldog trap for possums is currently patented in New Zealand and the United States and maintains 35% of the New Zealand possum kill trap market. The Dominus trap superseded the Thumper trap and is currently sold as a rat and stoat trap in New Zealand. The Hammer trap is being developed as a multi-species, multi-kill trap. The concept traps were developed to demonstrate how the inventive methodology can be applied to existing traps.

This thesis points the way forward to techniques to improve the efficacy of kill traps and the potential to build on this research as a means of achieving a multi-kill trap along with questioning the effect that NAWAC regulations has had on New Zealand trap development now and in the future.

Keywords: Humane trap, animal trap, trap design, comparative trap evaluation, action research.

Acknowledgements

Looking back over the project I realise how ambitious it was, not only from a funding standpoint, but also the amount of time by others that has gone into the project. There are simply too many people to thank individually.

I would, however, like to thank my supervisors Prof. Ken Hughey and Dr James Ross who have provided direction to the thesis and given their time freely. I only hope that I can do the same for other students in the future with such skill.

Finally to my wife, Vera, who has had to put up with talking and living traps for the past few years and her continuous support, I give my thanks.

Table of Contents

List of Tables

List of Figures

Chapter 1

Introduction

Chapter Overview

This chapter introduces the problem (section 1.1) caused by the introduction of vertebrates into New Zealand and their affect on conservation and the agricultural sector. Section 1.2 backgrounds the regulatory changes (Animal Welfare Act, 1993) and the impact these regulatory changes have had on pest control methods along with presenting the aims of this thesis. The objectives to achieve this aim are outlined in section 1.3, with section 1.4 describing the research approach. The chapter finishes (section 1.5) with a presentation of the complete thesis outline being presented.

1.1 The Need for Vertebrate Pest Control

While New Zealand's geographic isolation has afforded the country protection from a number of adverse biological influences (e.g., snakes), the country has never-the-less suffered from the ravages of exotic plants and animals. New Zealand's ecosystems evolved in isolation from the rest of the world, in the absence of many predators and competitors (King, 2005). This isolation helped produce a unique floral and faunal biodiversity, but one that is inherently vulnerable to introduced terrestrial weeds and vertebrate pests (DOC & MfE, 2000).

Most terrestrial weeds and vertebrate pests (Littin et al., 2004) present in New Zealand are the result of intentional introductions. Environmental weeds have been introduced into the native flora via invasion from exotic forests or 'garden escapes' (Timmins, 2004), while animals have mainly been introduced as a commercial venture (e.g., possum *Trichosurus vulpecula*) or as game species (e.g., Himalayan tahr *Hemitragus jemlahicus*). A few animal pest species are the result of ill-considered attempts to deal with problems arising from prior introductions, e.g., mustelids (*Mustela* spp.), which were introduced to control a booming rabbit (*Oryctolagus cuniculus*) population (King, 1984). The introduction of the possum and mustelids (mainly ferret *Mustela furo*) provided a vector for the transmission of *Bovine tuberculosis* (Tb) to other animals, which threatens the economic viability of New Zealand's animal farming sector (Livingston, 1996).

The ability of possum and ferret to distribute Tb is a threat to New Zealand's export meat market. The main area of concern is the South Island's West Coast, which has 48% of New Zealand's Tb problems (Cowan & Clout, 2000). Stoat (*Mustela erminea*) have now been found with Tb (G. Crossett, pers. comm., 2005), and this is probably the greatest vector threat for the spread of the disease, since a stoat's home range is about 50 ha for females and 100 ha for males (Gillies, 1998). In contrast, the home range of a possum is 25 ha. Ferret home ranges can also be large (180 ha) (Gillies, 1998), but ferrets tend to only penetrate forested areas up to 500 m. They cannot climb trees, and therefore concentrate on the fringes of the forest. Accordingly, stoats pose a far greater risk of spreading Tb because they move quickly between forested and farmed country (G. Crossett, pers. comm., 2005). Accordingly, to ensure the survival of vulnerable native flora and fauna or for Tb vector control, many of the introduced vertebrates require ongoing control measures, such as poison application, shooting, trapping and exclusion fencing.

Worldwide the use of leg-hold traps for furbearers has attracted particular attention from animal welfare groups (Muth et al., 2006) mainly due to the very visual nature of animal suffering, not helped by the fur being used in the fashion industry. In New Zealand the primary concern is sustained control of vertebrate pests with a secondary industry being the development of a furbearer trade for possums. In the next section I outline how these public issues have led to major research themes and ongoing management problems.

1.2 Background and Research Problem

Often animal welfare legislation has excluded pest control (Littin, 2005), which leads to some wild animals being treated in an inhumane manner. The extent to which people think animals should be protected varies. Regan (1985) and Singer (1993) think that the death of all animals should be treated in the same manner. However, there is also the "Animal Farm"- type view that "some animals are more equal than others" (Orwell, 1945). For example, recently in Australia, a Northern Territory Member of Parliament suggested that people should attack cane toads with cricket bats and golf irons because the toads were a pest that needed eradication. "Welfare rights of native animals have to be considered before the rights of cane toads" (Tollner, 2005, ABC Local Radio, 11 April).

New Zealand's Animal Welfare Act 1999 (AWA) addresses this imbalance between the rights of farmed animals and vertebrate pests by putting their welfare on an equal footing. The

AWA is administered by two committees, the National Animal Ethics Advisory Committee (NAEAC) and National Animal Welfare Act Committee (NAWAC). The use of traps is covered by the NAWAC draft guidelines (Anon, 2000), which have classified traps into two groups; being kill traps and non-kill traps. This thesis concentrates on the development of new kill traps.

New traps are continuously being developed for possums and ferrets in New Zealand, but with few of these ultimately becoming available commercially. This is due to the large investment required in research and development, and the need to displace or compete with existing traps on the market. The AWA 1999 (Anon, 1999a) provides a window of opportunity for new traps to replace existing traps that do not meet the humane levels designated by the NAWAC guidelines. However, there are market barriers towards welfare-product innovations (Binnekamp & Ingenbleek, 2006), as they require education and acceptance of the need to change on the part of the manufacturer, retailer and consumer.

Historically, traps were bulky and heavy, requiring the cutting of tracks or the use of helicopters for installation. This typically results in a static defence system rather than a mobile one. Many of the new designs that have passed the NAWAC guidelines have perpetuated bulky and heavy traps. A similar situation exists in Canada (B. Warburton, pers. comm., 2004).

Given the above issues the major reasons for my research are to:

- Develop a methodology to improve the design of kill traps that achieve humane standards (as defined by NAWAC; Class A and B)
- develop a system to increase the efficacy of kill traps, as trapping is currently a very expensive means of pest control, when compared to toxic baiting.

1.3 Aims and Objectives

Whitehead (1925, p. 95) stated "that the greatest invention of the nineteenth century was the invention of the methodology of invention" yet there has never been a methodology developed for the invention of animal traps. Thus, the aim of this thesis is to: identify and modify a design methodology suitable for the invention of cost-effective animal kill traps and develop a methodology for the comparison of traps, all consistent with the intentions of the AWA 1999.

Objectives

Given this aim there are five key research objectives:

I. To review the literature to establish the parts of a design methodology suitable for the invention of animal traps

II. To identify and further develop a design methodology suitable for the invention of animal traps

III. To demonstrate the design methodology by applying it to the design of traps for vertebrate pests

IV. To trial and revise the design methodology

V. To develop, test and revise a system for the comparative evaluation of kill traps.

Objective III requires further sub-objectives as the information on trap design relates to specific targeted vertebrate pests. These are broken down into trap sub-objectives:

- Determining the strike location (i.e., the part of the animal that is most vulnerable) of target pests that make them particularly susceptible to being killed humanely
- The testing of prototype traps on pest species to achieve a Class A or B classification under NAWAC guidelines
- To develop a means of comparing one trap against another.

Specific trap tasks are:

- To determine factors which effect the efficacy of traps
- To determine the longevity of traps that have passed NAWAC guidelines
- To focus on possum, ferret and stoat.

1.4 Research Approach

This thesis provides a clear structured inventive design methodology (see chapter 3) applied to the development of humane animal traps. My research approach required this inventive methodology to be integrated with the biology, ecology and behaviour of animals towards animal traps. There was a void of base information, e.g., when will an animal use a paw to retrieve an object as opposed to using their mouth in a particular situation? This base information is imperative for trap designers and required the undertaking of experiments and discussions with experts or with field operators. I believe that many traps have been engineered but few actually designed. The design of a successful animal trap, in my opinion, requires a multidisciplinary approach (e.g., ecologists, commercial trappers and biologists), which was achieved by incorporating Cooperative Inquiry into the inventive methodology. The inputs of these sources (via Cooperative Inquiry) are often difficult to quantify, but possible, and I have listed these inputs as personal communications.

As the thesis progressed the inventive methodology was modified to incorporate the natural behaviour of animals that may make them more prone to capture, e.g., stoats like running through tunnels.

The trap testing and field trials were conducted by independent people to ensure a clear distinction between developer and evaluator. This was to ensure that there could be no question regarding bias in the results from the developer. Humaneness testing of traps is expensive (approximately $10,000+ per trial), which tended to push towards over-design of the killing mechanism and as previously noted (p 3) results in large, bulky traps. My approach is to try and keep the traps as small as possible which relies more on animal orientation and strike location. This runs the costly risk of having to repeat the animal testing programme to obtain a satisfactory humaneness classification as opposed to creating an oversized trap for the target species. To aid designers a review of trap size to target animal was conducted as a design indicator (Table 11). All trap testing was conducted by Manaaki Whenua Landcare Research Ltd under animal ethics approval number 99/1/1. The humaneness testing provides a "stop" in the design process as shown in Figure 1. Therefore, the research approach was that the developed trap must pass the NAWAC humaneness testing before the design could progress.

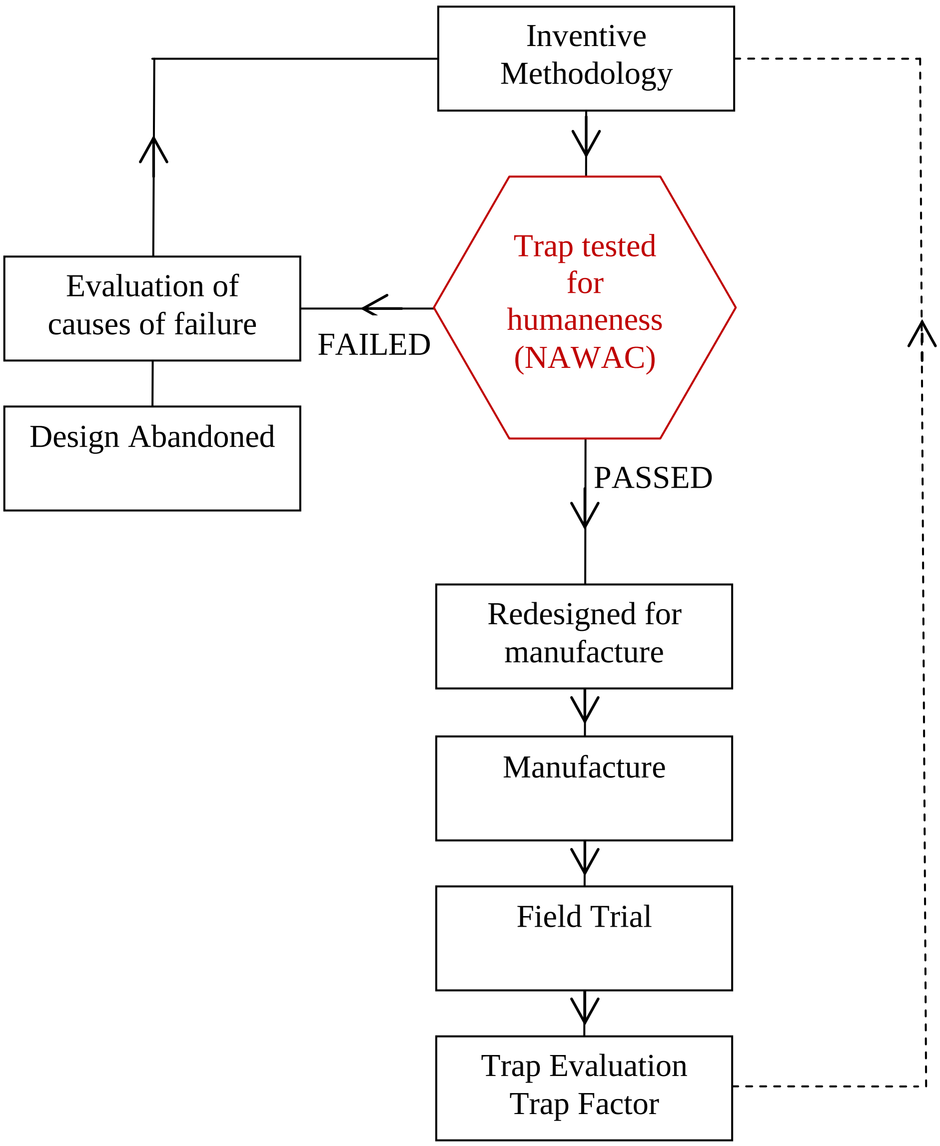


Figure 1 Trap development model

When observing animals prior to testing, and their approach to traps, it became very apparent that their behaviour was not always as expected, e.g., a stoat burrowed under a trap and entered from below. It was also a concern that the ultimate judge or failure lay with animals, which had already been caught once and may behave differently to repeat exposures to traps.

The commercialization of the developed traps was problematic with manufacturers/marketers having little understanding of the complexity of something that "appeared" so simple. Consequently, it was imperative that the developer was involved in the manufacture of the first production runs for field trials, to the extent that I created my own company (NZ Trap Ltd) to manufacture and assemble traps. This was an aspect of the research I had not anticipated.

To comparatively evaluate traps I developed an evaluation system called the “Trap Factor” that allows not only for two types of traps to be compared but also an entire trapping system. The importance of the Trap Factor for a trap designer, was that it could identify areas of good or bad performance; for a researcher, it provided a holistic technique to compare traps. The development of the Trap Factor neatly closes the thesis design package as shown in Figure 1. Ultimately then, the sum of these combined approaches is a thesis that is built on multi-disciplinarity. As such the thesis is not an engineering thesis, nor is it an ecology or social science thesis. Rather, the thesis is one of integrated design incorporating elements from disciplines including engineering, ecology and social sciences – its overall contribution to the sum of knowledge should be considered in this context.

1.5 Thesis Outline

Chapter 1 has provided a brief introduction to the vertebrate pest problems faced by New Zealand and introduced the aim, objectives and the research approach to this thesis. Chapter 2 summarises current knowledge and investigates the framework within which trap development is conducted both in New Zealand and internationally. Following this is a detailed explanation (chapter 3) of the prototype development methodology, a technique to evaluate new kill-traps developed as part of this thesis, a methodology to measure static clamp, and statistical data analysis used in this thesis. The prototype development methodology comprises a blend of Action Research and mechanical prototype development. The Action Research was challenging to undertake and difficult to report as the style of action research changes throughout the project and often occurs in a verbal manner. The prototype development methodology is then applied to vertebrate pest species and prototype kill traps are then developed (chapters 4-11). Traps are then tested on the target animal to determine the trap classification as prescribed by the NAWAC draft guidelines. Traps were then field trialled to determine the consistency of their strike location and ability to catch the target animal. As well as humaneness, there are other considerations that must be considered when comparing one trap with another as part of the development process. For this reason I introduce an equation called the “Trap Factor”, which attempts to quantify these considerations.

From the knowledge gained during the development of kill traps, the prototype development methodology is revisited and an additional component is introduced. I termed this additional component the “natural key”. The natural key “unlocks” the natural instinct of an animal, allowing the designer to consider the target animal’s instinctive behaviours as the focal point of the trap design. To demonstrate this methodology a rat trap was designed using the natural key (chapter 12). The historical evolution and manufacture of the padded leg-hold trap is presented in chapter 13; to demonstrate the incremental nature of trap development. Chapter 13 concludes by investigating if the Trap Factor can be applied to entire trapping systems; thereby, providing an indication to trap designers areas where improvements could be made. The rate at which traps lose their strength was then investigated in chapter 14, as this has implications for their ability to kill in a humane manner in the future. The conclusion and implications sections then follow in chapter 15. This involves reviewing the traps developed and from the knowledge gained points the way for further potential research. The development of the kill traps as part of this thesis has resulted in a number of awards and patents, which are also presented in this chapter.

Chapter 2

Literature Review

The purpose of this chapter is to first review the problems faced in protecting New Zealand's flora and fauna from predation by introduced mammals. The chapter then critically reviews the control measures used to limit predator populations, with a focus on trapping and the issues faced in trapping.

The key animals that the thesis concentrates on are all introduced, i.e., stoats, ferrets and possums; the reasons for each animal's introduction to New Zealand, and control measures to limit their populations are provided in sections 2.2-2.4. Following these introductory sections, section 2.5 then builds on the subject of control measures by looking at how society reacts to animal control. This is important, as societal concerns will ultimately determine what methods of control can be used. Building on societal views of pest control, section 2.6 then looks at the legislative framework governing traps and trapping in New Zealand.

Having now developed the need and discussed societal views and the legislative response in section 2.7 we then look at trapping standards around the world and compare these to New Zealand standards. As a result of the AWA, there are some existing traps that are proposed to be banned. These traps are presented and discussed in section 2.8 as this banning represents a lower threshold level of humaneness, which is acceptable under New Zealand legislation and to animal welfare groups. With the lower threshold developed the literature reviews the protocols currently used for trap testing in section 2.9. The approach used for the development of new traps around the world is then presented in section 2.10. The chapter then concludes with section 2.11 which integrates the key findings and shows the way forward to develop humane animal traps and provides a sense of direction for the remainder of the thesis.

2.1 Pests in New Zealand

Many of New Zealand's bird species, including kiwi (*Apteryx* spp.), kākāpō (*Strigops habroptilus*) and takahē (*Notornis mantelli*), have lost the ability to fly. Before human settlement there were no large land-based mammal predators, and the only mammals present were small native bats (*Mystacing* spp.), which posed no direct predation threat. With the arrival of the Polynesians 35 bird species became extinct, mainly the moa (*Dinornithidea* spp.), duck (*Anatidae* spp.) and goose (*Anatidea* spp.) species with a further 15 species since the European arrived (Gill & Martinson, 1991). With the settlement of New Zealand came introduced predators, which now require intervention to protect New Zealand's native wildlife. There are over 50 pest species recognised as needing to be controlled or eradicated to achieve this protection (Littin et al., 2004, p. 3). The major predators of bird life are: the hedgehog (*Erinaceus europaeus*), ship rat (*Rattus rattus*), stoat (*Mustela erminea*), weasel (*Mustela nivalis*), ferret (*Mustela putorius furo*), cat (*Felis catus*) and possum (*Trichosurus vulpecula*) (King & Moody, 1982; King, 1984; Flannery, 1994). Stoat, ferret and possum are primarily focused on in this thesis, as traps designed to catch one of these animals may or may not successfully and humanely trap other pests. For example a stoat trap will catch a rat, but a rat trap may not catch a stoat (Warburton et al., 2002). The introduction, animal behaviour and control measures of these three key species are now discussed.

2.2 Stoats

Stoat (Figure 2), from the family *Mustelidae*, are small mammalian carnivores, which are widely distributed throughout the Northern Hemisphere (King, 2005). They were first introduced into New Zealand from Britain in 1884 as a biological control agent for rabbits (*Oryctolagus cuniculus*), despite widespread opposition from ornithologists (Basse et al., 1999; King, 2005). Rabbits had become a major agricultural pest following their introduction. Run holders and some government officials believed that introducing rabbits' natural enemies—stoats, weasels, and ferrets—would alleviate the problem (Murphy, 1992). It soon became evident that these mustelids would not provide the control needed to end the rabbit problem (King, 1989). Stoats in particular invaded lowland forests and found easy prey among New Zealand's many species of ground-nesting and cavity-nesting birds (King, 2005). It was not until 1936 that all legal protection for mustelids was removed and they were officially recognised as pests (King, 2005).

Stoats are the most common carnivore in New Zealand forests (Wilson et al., 1998). They now occur in a wide variety of habitats from open pasture to dense forest; from sea level to above the tree line (King, 2005). However, stoats are absent from most offshore islands, except those within swimming range (up to 1.2 km) where they have become self introduced (Taylor & Tilley, 1984). Stoats are active hunters. They typically have a long thin body shape, are particularly flexible (King, 2005), and are active climbers, searching through every possible cover and down every possible tunnel (Simms & Craig, 1998).

The Department of Conservation (DOC) is now responsible for stoat control in areas that DOC administers where stoats are considered to threaten the survival of native birds and other animals. At present, predation is a major threat to the survival of kōkako (*Callaeus cinerea wilsoni*); black stilt (*Himantopus navaezelandiae*); kākāpō; hōiho or yellow-eyed penguin (*Megadyptes antipodes*) (Moller et al., 1999); yellowhead or mōhua (*Mohoua ochrocephala*) (O'Donnell et al., 1996); North Island brown kiwi (*Apteryx australis mantelli*); great spotted kiwi (*Apteryx owenii*) and kākā (*Nestor meridionalis*) (Basse et al., 1999; Morehouse et al., 2002). Other species vulnerable to predation include the Okarito brown kiwi or rowi (*Apteryx rowi*) (Miller and Elliot, 1997); New Zealand dotterel (*Charadrius obscurus*) (Dowding & Murphy, 1996); Caspian tern (*Hydroprogne caspia*) (Barlow, 1995); weka (*Gallirallus australis*) (Beaucamp et al., 1998) and banded dotterel (*Charadrius bicinctus*) (Sanders, 1997). Nesting females are particularly vulnerable to predation (O'Donnell, 1996) and this can cause a skewed sex ratio towards males (Wilson et al., 1998). Control is most effective when conducted over short periods when species in need of protection are at their most vulnerable; i.e., during breeding (King, 1984).

2.2.1 Control of Stoats

The stoat has a large home range, with males (223 ha) generally having around twice the range of females (94 ha). The reason for this is that the males are actively searching for females to breed with (Alterio, 2006).

Figure 2. Stoat (*Mustela erminea*) perched on a nest box (courtesy of the Department of Conservation)

Several aspects of stoat biology make stoats particularly resistant to control. First, they have the capacity to rapidly increase in population in response to increased food availability (King, 1989). Females are pregnant all year round; so control operations that kill a high proportion of the available males have no effect on the populations' reproductive potential (McDonald & Lariviere, 2001). Second, female stoats can be xenophobic to traps during spring (Dilks et al., 1996). Stoats have a high natural mortality rate (King, 1984) and even though higher kill rates are achieved in summer and autumn, this has little effect on the population because it is simply removing animals that would soon perish anyway, a principle known as "compensatory mortality" (Rate, 2008).

Boutique poisons (Spurr, 1998) designed to kill stoats are currently being developed, e.g., para-aminopropiophenone (PAPP) (S. Hicks, pers. comm., 2007). When rat control operations are conducted using 1080 or anticoagulants, there is the possibility of secondary poisoning as a result of stoats eating rats or mice that have been poisoned (Murphy et al., 1999).

Trap-based control operations (King, 1980) attempt to exploit stoats' inquisitiveness towards tunnels with the primary trap being the Fenn (King & Edgar, 1977). Trapping is "expensive"

(Moller & Alterio, 1999, p. 165), "time-consuming" (Dilks & Laurence, 2000, p. 173), short-term and only partially effective (Moller et al., 1992; Moller & Alterio, 1995; Moller et al., 1996) as there are always some stoats that will not get caught. For example, female stoats are inherently difficult to trap in spring (Dilks et al., 1996).

Some of the traps used on stoats include, Fenn, cage traps, Duncan tunnel, Victor rat traps and more recently the DOC 200 (www.predatortraps.com) and the traps identified in chapter 4 (Thumper, Dominus and Hammer). The techniques to improve catch rate are; better trap location, bait used (fresh rabbit preferred), walking dragging a dead rabbit behind, using gloves (to prevent scent) and hazing and hanging feathers above trap (D. Hunter, pers. comm., 2004). "The most commonly used baits at present are hen eggs which can last up to a month in cool climates" (King, 2005, p. 286). However, the most effective bait for stoats can vary between locations, with salted meat catching at higher rates than hen eggs in many locations (Miller, 2003; D. Blair, pers. comm., 2006).

Lessons from the Literature

The literature indicates that control needs to target the female stoat, especially over the winter months. If a large population of female stoats were successfully targeted this should cause a dramatic reduction in the stoat population. The literature gives no indication about how to catch female stoats even though this is the most obvious control measure, i.e., kill the breeders. The literature explains the problems of skewed sex ratios, but never tries to apply it to the predators and instead looks at the predated. The literature questions the timing and effectiveness of control measures along with explaining that stoats have a large home range. The literature indicates that stoats are inquisitive towards tunnels, yet few traps incorporate this behaviour in their design. Stoats prefer rabbit yet from personal observation many DOC trap lines fail to trial other baits and persist with the use of eggs, which the literature has shown can lower trap efficacy. The literature hails the success of eradicating rats and stoats from offshore islands and yet due to continuous re-invasion or "trap-shy" animals we are incapable of eradication of stoats on both the North and South Islands. Given that we are not eradicating stoats then the logical question is: are we just sustainably harvesting stoats at a level requiring continuous intervention?

Lesson for Thesis: *Can the fact that stoats are inquisitive towards tunnels be incorporated into a trap design*.

Lesson for Thesis: *The bait used has an influence upon the performance of a trap.*

Lesson for Thesis: *If we can better target female stoats this may have a devastating effect on the survival of stoats in the wild.*

2.3 Ferrets

Ferrets (Figure 3), like stoats, were introduced to control rabbits (Lavers & Clapperton, 1990), and New Zealand is now thought to support the largest population of feral ferrets in the world (Nowak & Paradiso, 1983; Cross et al., 1998). Although ferrets rely on lagomorphs (rabbits and hares) (Norbury & Heyward, 1996) for the staple component of their diet, they also eat hedgehogs, birds, invertebrates, and lizards as opportunity offers (Smith et al., 1995; Pierce, 1996). Ferrets have been trapped in North Island forests (King et al., 1996; Gillies, 1998), but their preferred areas are forest margins and anywhere lagomorphs live (Murphy, 1996; King, 2005). Ferrets have been implicated in the decline of a number of threatened ground nesting endemic species, e.g., black stilt (Murphy, 1996). Ferrets are also a vector (Sauter & Morris, 1995) for the spread of bovine tuberculosis (Bovine Tb) (Ragg et al., 1995; Livingston, 1996) and for this reason the Animal Health Board (AHB) funds ferret control to prevent the spread of Tb in several regions (Anon, 2001).

2.3.1 Control of Ferrets

The major system used for the control of ferrets is live capture or leg-hold traps (Calcy, 1996). There is currently no commercially available poison for ferret control although 1080 (Moller et al., 1996; Alterio, 2000) secondary poisoning (Alterio, 1996; Brown & Alterio 1996; Gillies & Pierce, 1999) successfully poisons ferrets. Trials have been conducted with other poisons, e.g., diphacinone, with varying success rates (Ross & Henderson, 2003). The spatial range of ferrets can be 12-288 ha (Moors & Lavers, 1981; Ragg, 1997; Medina-Vogel et al., 2000). Male ferrets tend to be more easily caught, which could be due to their larger home range (Clapperton, 2001). Traps used on ferrets include soft-jaw leg-hold Victor, (section 2.8.2), Timms (section 4.5), Conibear (section 7.2), Fenn (section 2.8.2) and more recently DOC 250 (www.predatortraps.com). These traps are typically baited with fresh meat (Moller et al., 1999), but catch rates can be improved if an attractant is also used (Clapperton, 1994). The timing of control operations is critical (Clapperton, 2001, p. 196) as early season trapping has no marked effects on predation rates for some species (Ratz, 2000). "Trapping rates are highest in late summer to autumn (Ragg, 1997), but this may not be the best time to trap" (Clapperton, 2001, p. 197), for similar reasons as for stoats (King, 1984), as mentioned in section 2.2.1 above.

Figure 3. Ferret (*Mustela furo*) (courtesy of the Department of Conservation)

Lessons from the literature

The female ferret, like the female stoat, is detailed in the literature as being difficult to catch. A possible explanation is the larger home ranges of the male ferrets, i.e., more chance of intercepting a trap. Like the stoat literature there are concerns about the correct timing of control operations to achieve species protection from predation. Studies have shown the ferret does not generally travel deeply into the forest due to its inability to climb and its preference for rabbits. Therefore, this means that an inner forest trap will not have to target ferrets. A strong funding source has been provided via the AHB with much of the literature concerned with ferrets as a vector for Tb. AHB control measures have been concerned with live capture so that biopsies can be conducted to determine the presences or absence of Tb infection (which requires recently killed animals). The use of kill traps will increase as the need for biopsies decreases mainly due to the checking requirements of the NAWAC guidelines (Anon, 2000).

Lesson for thesis: *There will need to be two traps, an inner bush targeting solely stoats, and an open farm land trap targeting both ferrets and stoats.*

Lesson for thesis: *The demand for kill trapping will increase due to a reduction in the number of biopsies required and the trap checking requirements of NAWAC.*

Lesson for thesis: *Ferrets prefer rabbit as bait and there is the potential for lures to increase catch rates.*

2.4 Possums

The brushtail possum (Figure 4) was introduced into New Zealand in 1837 (Pracy, 1974), in an attempt to establish a fur trade. By 1947 the government cancelled restrictions on the killing of possum and legalised the use of poisons for possum control (Montague, 2000). By 1990 possums had reached all parts of the North and South Islands (Cowan, 1990).

Figure 4. The brushtail possum (*Trichosurus vulpecula*) feeding on bread (source:Wikapedia, December 2008)

The possum generally has one young per year, which results in a population increase of 20-30% per annum (Barlow, 1991). They can live up to 14 years (Brockie, 1991), but have an average life span of six years in the wild. Most New Zealand vegetation has higher nutritional value than that of the possum's natural home in Australia (Freeland & Winter, 1975). Therefore, much higher population densities can be maintained. Also, the possum has fewer natural predators in New Zealand compared to Australia (Cowan, 1990). Possums have a home range of 245–295 m (8.7 ha) (Green, 1984) in bush and in open farmland this can extend to 1600 m (256 ha) (Jolly, 1976). "The possum is considered the primary wildlife reservoir of Bovine Tb for farmed cattle and deer in New Zealand" (Montague, 2000, p. 92). Tb-infected possum populations occupy about 24% of New Zealand's total land area (AHB, 1998). The estimate of the possum numbers in New Zealand range from 40-70 million with control in native forests generally being triggered by a population density significant enough to require intervention to limit their numbers. Note, it was not until the 1990s (Brown et al., 1993; Innes, 1995) that possums were recognised as major predators of eggs and nesting native birds.

2.4.1 Control of Possums

Since 1956, the major method of possum control in New Zealand has been aerial poisoning using 1080 (sodium monofluoroacetate). Kill rates of 80-95% are achieved as possums generally eat poisoned bait as soon as they encounter it (Morgan, 1982). The possum dies within 54 hours after receiving a lethal dose (Henderson et al., 1999). Other poisons include encapsulated cyanide (Feratox®, Connovation Ltd) and anticoagulant poisons (Eason & Jolly, 1993). "Although poisoning continues to be the most extensively used technique for controlling possums in New Zealand, trapping, shooting, chemical repellents and physical barriers are management tools used" (Montague, 2000, p. 164).

Historically the trapping of possums has concentrated on the use of Lanes Ace (gin) traps and later on variations of the "soft-jaw" leg-hold trap, e.g., Victor and Duke leg-hold traps. The possum is a relatively easy animal to catch due to its sheer numbers; however, in lower densities they can become trap and/or poison shy. The timing of possum control operations depends on the reason for control, e.g., for conservation this may be based on a vegetation damage threshold (Stevens & Barnett, 1998) and for Tb control it may be a continuous maintenance operation (e.g., every 1-2 years, J. Ross, pers. comm., 2009). Possums forage extensively on seasonally available food, e.g., apples or new shoots of poplar and willow (Jolly, 1976). From the literature there appears to be no high seasonal catch rate although there is data to show differing home ranges and feeding times throughout the year (Cowan & Clout, 2000). The possum is also harvested as part of the fur trade which uses a combination of leg-hold and kill traps. There is a demand for a multi-kill trap, however this needs to be economic compared to the option of having multiple single kills instead (B. Warburton, pers. comm., 2004). The use of electric shock (Dix et al., 1994) for humanely killing multiple possums has been developed to a commercial product and is available for approximately $700 per unit (Electropar Ltd NZ Pat 243915).

The first possum kill traps tested (Bayna, Bigelow, Conibear and Kaki) proved to be less trap efficient to possums and inhumane, frequently causing gross injuries to possums that were not struck in vital positions (Warburton, 1982). The Timms trap was initially thought to kill very effectively (Warburton et al., 2000), but has since failed the NAWAC testing (Appendix B), and compared to leg-hold traps the Timms trap is less efficient (Miller, 1993).

Lessons from the literature

The reviewed literature indicates that when attempting to kill very large numbers of possums the use of poison is the most economic method and the cost is low compared to that of using animal traps. However, the published research on toxins does not address the welfare of the joey in the pouch that will starve to death as a result of the mother being killed. Some kill traps can catch at higher catch rates than others yet no published literature gives a definitive reason of why this is so. There is also no clear indication from the literature as to what attributes of a kill trap will increase the efficacy. It is unclear that if possums are poison shy will they also be trap shy.

Lesson for thesis: *Possums in low density potentially may be poison and/or trap shy following control operations.*

Lesson for thesis: *Possums need to be struck in a vital area, usually the wind pipe or carotid artery.*

Lesson for thesis: *Multi-kill traps will need to be developed that are cost effective.*

2.5 Social Aspects of Pest Control

Maori, New Zealand's indigenous people, relied on the land to provide food. Often the debate over hunting (including the Maori issues of cultural harvest, e.g., kereru), moral, ethical and management issues receive much more weight than cultural importance (Finn, 1997). The cultural affiliation to animals differs between indigenous people (Flannery, 1994), and may be one of equal footing to humans (Sioux Indians), harvestable food source (Maori) and farm raised ("Animals, who we have made our slaves, we do not like to consider our equal", Darwin notebooks 1837).

The degree of debate over moral, ethical and management issues is typically based upon the wealth of a country. For wealthy countries the "moral" animal rights activists are generally described from demographic surveys as being urban residents, with a comfortable income (Richards, 1991), who have strenuous ethical objections to traditionally acceptable methods of harvesting of wildlife through hunting and trapping (Proulx & Barrett, 1991a; Richards & Krannich, 1991). So, as concluded by Litten & Mellor (2005, p 767):

> "The differing degree to which today's cultures rely on wildlife has led to a conflict of ideologies on the use of wildlife" (Warburton, 1998a, p. 131). However, the "ethical and animal welfare concerns about the destruction of free–living wildlife for disease control and environmental reasons have historically received little attention".

The deliberate killing of animals mandated through legislation (e.g. Wild Animal Control Act 1993), has determined that some introduced animals are pests and where their damage is judged to be sufficient, lethal control is required and legal (Warburton, 1998a).

A clear majority (88%) of the New Zealand public feels that control should comply with a standard of humaneness (Fraser, 2001). Social research (Fitzgerald et al., 1996; Morris & Weaver, 2003) has shown that some form of reproductive control is the preferred control option (Cowan & Tyndale-Bisco, 1997; Cowan, 2000; Norbury, 2000; McDonald & Lariviere, 2001). However, reproductive control has not yet been developed to a commercial degree for the pests reviewed here and other control measures are required in the interim. New Zealand farmers perceive shooting as the most humane and safe method for controlling rabbits (Wilkinson & Fitzgerald, 1998); "while viral diseases were seen as the most effective" (Henning et al., 2005, p. 171).

"Historically, public concern about humaneness of methods used to control unwanted wildlife has focused on leg-hold traps, and less humane poisons, such as arsenic and phosphorous", (Littin & Mellor, 2005, p. 771). The greater use of non-lethal methods such as repellents (Gregory, 2003), "exclusion fences" (Montague, 2000, p. 170), guards (Thomas & Warburton, 1985), or relocation pose little public concern. The justification for control may be easily accepted in some cases. For example, the outbreak of a disease such as foot-and-mouth may lead to the killing of many animals as a means of containing an outbreak; as occurred recently in the United Kingdom. Killing numerous pest species to protect a few endangered native animals (Marks, 1999), may not be easily accepted (Littin & Mellor, 2005). Control measures often pose risks to both target and non-target animals. The effects on non-target animals is often a cause for public concern, e.g., the use of 1080 poison and its perceived effect on, native bird life (Cook, 2008) and drinking water quality (Suren, 2006).

New Zealand, given the risk to the natural environment, is more accepting of the need for wide scale pest control than many overseas countries, and preservationist ideals have come to dominate New Zealand terrestrial biological conservation legislation (Eggleston et al., 2003) and practice (King, 1996). The desire to return to the "natural state", which is taken to be the conditions existing prior to human influence, has resulted in the fervent aim of eradicating all "foreign" introduced species from protected lands (Eggleston et al., 2003). Without human intervention there would be a massive ecosystem change (Parkes & Murphy, 2003), due to predation on native species from introduced pests.

Lessons from the literature

This research indicates a clear need for developing means of killing which are socially acceptable and humane, with a dislike for the use of leg-hold traps and a clear preference for reproductive control (Wilkinson & Fitzgerald, 1998).

Lesson for thesis: The use of fertility control is the most socially preferred method but has yet to be developed as a commercial pest control technique for New Zealand vertebrate pest species.

Lesson for thesis: The more visual (to the public) the form of death the quicker it needs to be.

2.6 Legislation and Pest Control

New Zealand pest-control legislation concerns two principal areas of interest (Littin & Mellor, 2005), being; 1) species protection, biodiversity conservation and human health; and 2) management of the species to be controlled in New Zealand. These aims are regulated by the following four Acts:

- *Wildlife Act 1953*
- *Wild Animal Control Act* 1977
- *Biosecurity Act 1993*
- *Animal Welfare Act 1999.*

All these Acts affect how pest control is conducted in New Zealand. The Wildlife Act 1953 protects some wildlife while allowing for "restricted or unrestricted hunting" of some species. The Wild Animal Control Act 1977 allows for intervention if a species is in need of control, e.g., rabbits; however, it does not cover stoats or ferrets. The Biosecurity Act 1993 aims to protect New Zealand's biodiversity from invading organisms. The Animal Welfare Act (AWA) 1999 replaces the "Animal Protection Act 1960, which no longer met the expectations of New Zealanders or international consumers" (Anon, 1999b, p. 1) and ensures fair treatment of animals, both farmed and controlled. Because the AWA lacks detail, a guide has been prepared outlining how it should be interpreted (Anon, 1999b).

Two sub-committees also help implement and administer the AWA. They are:

- The National Animal Ethics Advisory Committee (NAEAC). NAEAC advises the Minister of Agriculture on ethical issues and animal welfare issues arising from research, testing and teaching (Hoadley, 2003, p. 38).
- The National Animal Welfare Advisory Committee (NAWAC). This committee creates guidelines on levels of acceptable animal welfare for both farmed animals and wildlife.

The major influence on the use of animal traps is via the NAWAC guidelines for mammalian restraining and killing traps (Anon, 2000).

The AWA (1999) does not differentiate between pest and non-pest animals. Therefore, the same ethical considerations must be applied to both, despite evidence that the public values possums significantly less than kiwi and takahe (Hickling, 1994). In contrast, in 1998 the United States Department of Agriculture (USDA) definition of animal (according to Becker 2008, p. 4) is:

> "The act applies to any live or dead dog, cat, nonhuman primate, guinea pig, hamster, rabbit, or other warm-blooded animal determined by the Secretary of Agriculture to be for research or exhibition, or used as a pet. The AWA (USA) explicitly excludes birds, rats, and mice bred for research; horses not used for research; and other farm animals used in the production of food and fibre. Animals sold in retail facilities are not covered, unless they are wild or exotic animals. Cold-blooded animals like fish and reptiles also are excluded from coverage."

Activists have successfully taken legal action against the USDA for rats, mice and birds to be covered by these rules.

In 1983 in Toronto, the Canadian delegation suggested developing a standard for humane trapping at the Conference on International Trade in Endangered species (CITES) (Warburton, 1998a, p. 133). Setting performance criteria for kill traps is arguably easier than setting performance criteria for restraining traps (Powell & Proulx, 2003, p. 260) because unconsciousness and death are relatively easy to define objectively, compared with the injury and anxiety that restrained animals may experience. The Canadian General Standard Board adopted the criterion that a humane kill trap must render the animal unconscious and unable to recover within 3 minutes. "To some ethicists, 3 minutes is unduly long, yet it is a realistic time that pushes current technology" (Powell & Proulx, 2003, p. 260). The criterion that was proposed by Canadian researchers Proulx & Barrett (1994) for adoption, was:

> *Criterion I* - for kill traps: State-of-the-art kill traps should, with 95% confidence, render > 70% of caught animals irreversibly unconscious within < 3 minutes.

Lessons from the Literature

The literature outlines the shortfalls of previous legislation prior to the AWA that excluded pest animals and suggests that we need clear trapping standards.

Lesson for thesis: A kill trap needs to meet the humane requirements as described by NAWAC.

2.7 Trapping Standards

There are three standards for animal trapping: the Agreement on International Humane Trapping Standards; the 1994 International Organization for Standardization (ISO) Draft Standard and New Zealand draft standards. These trapping standards are summarised in Table 1.

Table 1. Trapping Standards (Warburton 1998a, p. 135)

Agreement on International Humane Trapping Standards (1998)	**1994 ISO draft standards**	**NZ draft standards (1998)**
The term "humane" used	"Humane" removed	"Humane" removed
No party may impose restrictive trade measures on fur or fur products from any other party	No trade issues	No trade issues
Thresholds for restraining traps. Sample of at least 20 animals 80% of animals must show no indicators of poor welfare	Sample of at least 25 animals. ≥80% of trapped animals must have injury scores less than 75. (Now removed)	With 90% confidence, ≥ 70% trapped animals must have no or only acceptable traumas
Thresholds for kill traps Stoats (*Mustela erminea)* 45 sec. Marten/Sable *(Martes* spp.) 2 min. All others 5 min (3 yr review)	Class A. With 90% confidence, ≥70% of animals rendered unconscious within 3 min	Class A. With 90% confidence, ≥70% of animals rendered unconscious within 30 sec.
At least 80% of animals rendered unconscious within the time-frame	Class B. As with Class A, but within 5 min.	Class B. As with Class A, but within 3 min.
Physiological/behavioural studies recommended if ISO standard approved.	Physiological and behavioural studies recommended	Physiological and behavioural studies not mentioned

The key differences between these standards concern the acceptable thresholds for distress or injury for restraining traps, the kill times and percentage of animals rendered unconscious for kill traps (Iossa et al., 2007). NAWAC guidelines have the highest levels for acceptance, whereby all animals must be unconscious within 30 seconds for Class A classification. The other standards are three minutes for 1994 ISO draft standards; and for the Agreement on International Humane Trapping Standards (AIHTS), a class structure for time-to-death based on type of animal being caught. This latter standard does, however, require a higher minimum number of animals (20) to be tested than the NAWAC draft guidelines (10) ("the AWA 1999 came into effect on January 1, 2000", Biosecurity New Zealand). Fox (2006, p. 2) considered that:

> "the standards (AIHTS) were forced on these countries from the EU under trap directive regulation 3254/91 the 'leg-hold trap fur import ban' and was meant to prohibit use of leg-hold traps (Figure 5) in all EU member countries. Also to bar the importation of pelts from 13 species of fur-bearing animals from countries that still use leg-hold traps (the regulation was later expanded to cover 19 fur-bearing species)".

However, ratified international agreements cannot be "forced" on countries.

Figure 5. Fox caught in leg-hold trap (courtesy www.infurmation.com)

Currently the three nations with the highest incidence of fur-bearing animals (Canada, Russia and the United States) continue to use leg-hold traps (Anon, 2007b). Best management practices have been written for their use (Anon, 2007a). There have been modifications to the leg-hold trap, namely, a soft-jaw addition (Linhart & Dash, 1992; Tullar, 1984), and chain springs (Warburton & Pouto, 2008). However, there is still a call for a total ban on leg-hold traps by animal rights researchers and lobby groups (Fox, 2006; Muth et al., 2006), along with many anti-fur lobby groups, e.g., the Fur Free Alliance (www.infurmation.com). Note: 'leg-hold' is a generic term for a diverse range of traps not limited to the 'gin' traps, which tend to be animal rights groups' key concern. Many of these different types of leg-hold traps are described by Bateman (1973).

The testing programme for the compliance of traps to meet the kill thresholds (AIHTS kill traps) or severity of injury (restraining traps e.g. leg-hold or snare traps) was conducted in Canada (Jotham, 1987) and the United States.

Lessons from the Literature

The literature cites differing world-wide standards showing that such standards are subjective in nature. This is also reinforced with many "standards" removing the word "humane" which is a subjective measurement.

Lesson for thesis: Because a trap has achieved a "humane" standard in one country does not necessarily mean it will be considered "humane" in another country.

2.8 Non Kill Traps Proposed to be Banned in New Zealand as a Result of the NAWAC Draft Guidelines

In this section I review traps that are proposed to be banned by NAWAC because this establishes a boundary to what is unacceptable from a humaneness level irrespective of the efficacy. However, it is interesting to note that even though NAWAC has recommended that glue traps be banned they are still available for sale and MAF has still not moved to ban these traps.

2.8.1 Glueboard Traps

Glueboard traps (Figure 6) are currently available throughout the European Union and are not banned (Frantz & Padula, 1983). However, glueboard traps were tested on mice and out of 40 caught, 35 survived for more than 24 hours attached to the board (Biosecurity New Zealand, 2008), which NAWAC considered inhumane. Other traps like the Rat Zapper 2000 (Warburton & Pouto, 2002), have also been shown to be inhumane and procedures are in place to also ban these traps (B. Warburton, pers. comm., 2005). NAWAC's intention is to have in place a trapping regime, which is humane and has equivalent or better trap catch rates than existing traps (B. Warburton, pers. comm., 2005).

Figure 6 . Glueboard trap with rat "caught" (source: Wikipedia, February 2009)

2.8.2 Lanes-Ace (gin) Traps

The Lanes-Ace (gin) trap (Figure 7) has been banned from sale in New Zealand (NAWAC, 2007). Leg-hold traps are still used instead of kill traps in New Zealand's possum fur industry, as possum need to be plucked while still warm (www.merinopossum.co.nz). This prevents breakdown of the fur's hollow fibres. The RNZSPCA (Mason & Litten, 2003, p. 2) "would like to see a ban of all steel leg-hold traps without a soft catch attachment (piece of rubber attached to steel jaws)" (Figure 8). The early versions of soft catch were less efficient (Linhart et al., 1986, p. 212) than their solid-jawed counterparts. However, the catch rate has now been improved (Phillips, 1992, p. 393) and injuries reduced (Linhart & Dash, 1992, p. 63). The soft catch feature reduces (but does not eliminate) injuries to the animal (Olsen et al., 1986; Warburton, 1992).

Figure 7. Ace Trap (gin trap) (courtesy of Manaaki Whenua Landcare Research Ltd)

Figure 8. Victor No. 1 Soft Catch trap (courtesy of Manaaki Whenua Landcare Research Ltd)

It is generally perceived that traps set on the ground do not catch as many possums as those set in ‘raised sets’ in trees (Thomas & Brown, 2000, p. 6). For this reason many trappers use ground sets, which can endanger some native birds. In areas where traps are to be used on DOC land, traps must be raised 700 mm off the ground (Morriss et al., 2000). However, this causes a “four-fold increase in possums with broken bones, because they are often left dangling from the trap” (Thomas & Brown, 2000, p. 12). NAWAC guidelines require that a leg-hold trap is checked every day. This represents an increase in trap effort for a leg-hold trap over a kill trap, as a kill trap has no time requirement for checking. Prior to the NAWAC guidelines the traps of choice were the Fenn Mk 4 or Mk 6 kill traps (Figure 9) and leg-hold traps. The Fenn traps also have the capability to catch rats, hedgehogs, stoats and ferrets.

Figure 9. Fenn Mk 4 trap in set position (courtesy of Manaaki Whenua Landcare Research Ltd)

The Fenn Mk 4 (Figure 9) and Mk 6 traps were introduced from Britain in 1972 by Waikato University’s Dr Caroline King, and were the most commonly-used kill trap in New Zealand

(King, 1994) until the development of 2nd generation traps in the last five years. Fenn traps are most often used as a double set (Kirk & Gillies, 2008). This also has the potential to increase the catch rate (E. Murphy, pers. comm., 2003) since if one animal is trapped another will investigate and also get caught.

The Fenn trap is a "body-grip" trap. When an animal stands on the pan the trap jaws close resulting in the animal being caught about its body (Figure 10).

Figure 10. Fenn Mk 6 horizontal body strike on a stoat (courtesy of Manaaki Whenua Landcare Research Ltd)

<u>Lessons from the Literature</u>

The review of literature indicated that traps (gin) that were considered inhumane, with minor modification can be classified as humane (i.e., soft pads added). Accordingly the real issue is what is humane? It is currently too subjective, e.g., a leg-hold trap will pass a humane standard that looks at severity of animal injuries yet still be considered as inhumane by others. In the same manner a glue trap could be modified to act in a more humane manner, e.g., to have a poison exposed once the animal is captured that the captured animal would then eat. The banning of traps will need to ensure that it does not ban the principle of the trap operation as this could prevent future humane traps being developed, but rather the specific application of the method of capture.

Lessons for Thesis: It is essential that a design passes the NAWAC guidelines otherwise it could encounter market barriers in New Zealand.

2.9 Trap Testing

Internationally, trap testing covers all types of traps designed to restrain or kill mammals (Anon, 2002). It does not apply to poison traps (Marks et al., 2004), or tranquiliser traps (Sahr, 2000); however, due to the effects of some poisons, animals can suffer for days (Mason & Litten, 2003).

The Canadian Agriculture Department (Agriculture and Agri-Food Canada) developed a trap testing laboratory at the Alberta Environmental Centre in Vegreville, with a seven-step testing process (Jotham, 1987, p. 2).
This process involved:

- examining how an animal approached a trap
- allowing the animal to trigger the trap (but preventing it being struck)
- testing anaesthetised animals (in same position as initially triggered)
- kill tests on a limited number of animals
- traps being submitted to official kill test trials
- controlled field tests
- mechanical testing.

The American Best Management Practices (BMP) for traps has an evaluation of one trap (Anon, 2006), and any other traps that can equal the mechanical performance are by default acceptable for that species. The New Zealand trap testing system goes straight into killing animals and currently has no mechanical testing component. There are a limited number of agencies (such as Manaaki Whenua Landcare Research Ltd) authorised to conduct the tests. The actual number of animals selected must be ten or more. A trap's performance with this number would indicate a 70% probability (see Table 1) that it would perform to the same standard in the field. The European Union standard requires that 12 animals are used in testing. This results in a higher level of certainty (80%) (see Table 1). "The smaller the sample sizes, the more chance an otherwise acceptable trap could fail" (B. Warburton, pers. comm., 2004).

The following kill traps have been tested under New Zealand standards for stoats and rats:

- Victor Snapback (Warburton et al., 2002): passed for rats
- DOC 150/200 (Warburton et al., 2008) (predatortraps.co.nz): passed for rats and stoats

- Sturgeon (Poutu & Warburton, 2005): passed for rats
- Waddington backcracker (Poutu & Warburton, 2003): failed for stoats
- Fenn Mk 4 or Mk 6 (Warburton et al., 2008): failed for stoats (see Figure 10).

Even though a trap may have failed the NAWAC guidelines they can still be sold, e.g., Fenn traps. For the killing of ferrets only the DOC 250 (Appendix B) and the Hammer (section 8.7) trap passed the NAWAC draft guidelines, although many traps have been tested (Appendix B). For the killing of possums only the LDL 120 (Warburton & Orchard, 1996), and now the Warrior (formerly Bulldog) (section 7.9), Set and Forget traps (Appendix B) have passed.
Testing one trap on one species in Canada costs on average $40,000 CD (Fox, 2006, p. 20). There have been 153 traps tested in Canada with the traps that have passed the testing requirements listed online (www.fur.ca/index-e/trap_research). In New Zealand, the cost for a humaneness trial was NZ$19,000 for two ferret trials (J. Ross, pers. comm., 2008) and this cost does not include field evaluation.

Lessons from the Literature

The literature reports on traps needing to pass a "mechanical standard" and by default any trap that meets this standard passes in the United States of America. This approach does not take into account the triggering mechanism used or the approach of the animal to the trap. From the literature it indicates that the more animals we test the better the chance of replicating the trial results in the field. Yet NAWAC has a lower limit (see Table 1) compared to other international standards for the number of animals to be tested. The problem is that there is a jumble of standards throughout the world.

Lesson for thesis: The testing of kill traps can be very expensive and a trap that passes in another country may not necessarily pass in New Zealand.

2.10 Development of traps

Over 4000 trap patents have been issued in the United States and Canada (Stewart, 1977); others (e.g., Hellwig & Drummond, 1994) put this number at over 6000. The desire for humane traps had its roots in 1926 with the formation of the American Humane Association (AHA) (Linhart, 1985). The reason for this was to look into alternative replacements for leg-hold traps, which were considered to be inhumane (Linhart, 1985). Competitions were run with cash incentives trying to find suitable replacements and thousands of traps were submitted by 1936 (Anney, 1936 as cited in Gentile, 1983). However, no satisfactory alternative was found to replace the leg-hold trap. The competition approach has also been recently applied to the development of a cane toad trap in Australia (2007) and a wolf trap in America (2008) with the winners of these competitions currently being evaluated.

Canada, more than any other country, has sought alternative trap types, concentrating on kill-type devices (Linhart, 1985). A humane trap development committee (HTDC), initiated in 1968 and sponsored by the Canadian Association for Humane Trapping (CAHT) and other Canadian humane groups, has sought to develop humane traps (Jotham, 1994).

The Canadian experience in producing humane traps "was one of looking for the ultimate humane trap on the premise that some genius out there would produce the perfect trap. The design of humane traps became very apparent that there was a huge amount of work to be done to achieve this and it was likened to getting a man on the moon. For fourteen years Canadian humane societies attempted (unsuccessfully) to develop a scientific approach to humane trap development" (Manthorpe, 1981, p. 320).

Lesson for thesis: The development of "an optimal" methodology for trap design that meets a variety of key criteria, including humaneness has not yet been achieved.

2.11 Conclusions and a way forward

New Zealand has a dilemma, if it wants to maintain biodiversity and its agricultural base it must kill pests. With the introduction of the AWA and its wide definition of animals requires that all animals whether farmed or wild to be treated in a humane manner. Therefore, we must kill pests and do so in humane and socially acceptable styles.

The literature indicates a large number of patents (6000+) and yet we find ourselves looking for better humane traps. The quest for humane traps as a result of societal concerns leads us into a new era of animal trap design. The literature has identified a clear need for an inventive methodology for kill traps and to date no such methodology exists. The literature concentrates on the kill rates as a means of trap comparison and fails to look at other intrinsic features that I believe need to be addressed. This thesis develops a methodology to address this trap comparison imbalance.

Therefore, for kill traps the way forward is the development of an inventive methodology for the invention of new traps and a methodology to holistically compare new traps to existing traps.

Chapter 3

Methodology

3.1 Introduction

"From the Renaissance to the 1950s design was not visible to anyone but the designer, and sometimes they really did not know how they discovered the solution" (Jones, 1970, p. 2). In the 1950s, the concept of an open (documented) design methodology had not yet been developed. The research methodology used in this thesis to answer the research objectives is well defined and measurable. It is a combination of Action Research, Cooperative Inquiry, and application of the design process. Action Research is described by Dick (2008, p. 1) as: "a family of research methodologies that pursues the dual outcomes of action and research". Others (e.g., Rapoport, 1970, p. 499) expand the definition to include collaboration, "Action Research aims to contribute both to the practical concerns of people in an immediate problematic situation and to the goals of social science by joint collaboration within a mutually acceptable ethical framework". The collaboration aspect of Action Research can take different forms, e.g., PAR (Participatory Action Research) where participants are actively involved in the research (Flood, 1998), and Cooperative Inquiry. Cooperative Inquiry is "research *with* rather than *on* people" (Heron, 1985, p. 128) and the participants inputs are controlled by the researcher.

In the next section I present the design process as developed and used in this research (section 3.2), followed by the complementary concept of Action Research (section 3.3.1) which functions at each part of the design process alongside Cooperative Inquiry (section 3.3.2). The design philosophy (section 3.4) and methodology associated with each step of the design process (section 3.5) are then presented. This blend of methodologies will provide a structured repeatable system to channel the innovative design process. Also, techniques for comparing one concept against another (section 3.5.7) will be presented as a method of ensuring that the design with the highest potential advances to the manufacturing phase. A prototype kill trap will then be tested against NAWAC guidelines to determine its ability to kill target animals within the specified time. A new methodology is presented (section 3.5.12) as a means to evaluate the prototype trap against another existing trap, thus taking more into account than merely satisfying the NAWAC guidelines. A method to measure the strength of traps is presented (section 3.6) to investigate the rate at which traps loose strength overtime, due to overloading or hysteresis. The data analysis (section 3.7) outlines the statistical methods used in this thesis. A conclusion to the methodology chapter (section 3.8) rounds off the chapter.

3.2 The Design Process

The design process is a process aimed at developing knowledge that improves design performance in the world (Poggenpohl & Sato, 2003). Eekeles (2002, p. 615) found that: "Design is a creative process, which cannot be performed completely by deductive reasoning. At essential moments the designer has to take recourse to reductive reasoning steps". Without these reductive steps, there would be simply too much information. In contrast, Rodolph (2000, p. 1) identifies this stage as one of the major bottlenecks, "given the amount of design information, which the design engineer needs to take into consideration". At this concept design stage of the design process, it is essential that many design alternatives are critically evaluated (Whitefield et. al., 1999).

A graphical representation of the design process was developed by Rodolph (1995, p. 15) who states:

> "If, at the end of the design process, the actual complete object exists, then, at the beginning the designer only has an idea at their disposal. In the course of the design process, the intellectual conception of the designer is evolved at the same time as the formation of the object design parameters x_1, x_2 in time" (see Figure 11).

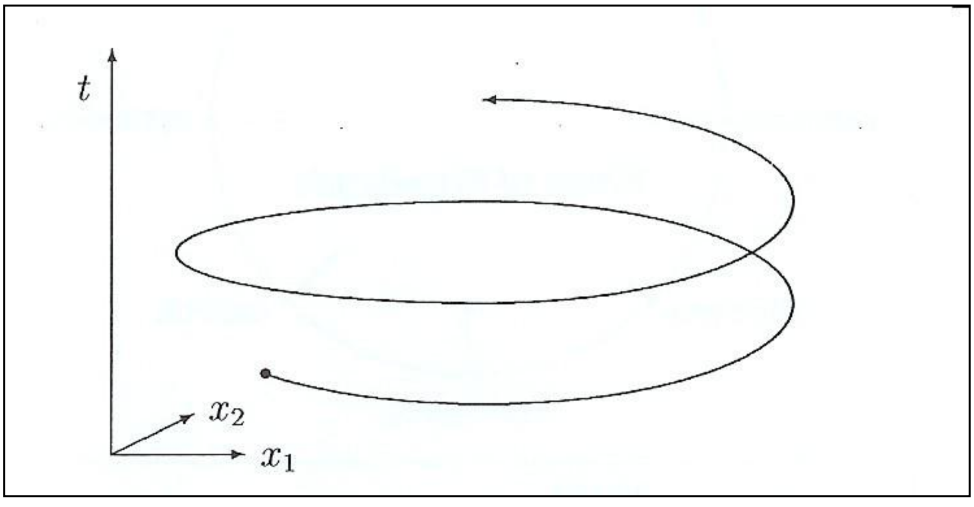


Figure 11. The design process (Rodolph, 1995) (x_1 and x_2 design parameters)

This loop-shaped design process involves influences such as functionality, material selection and cost which a design must take into account (Figure 12). The design process forms the structure of the loop, progressing through the iterations until an object is developed. Within each of these major design iterations there are separate spin-off loops that add to the process as the design progresses. These separate loops feeding off the design loops are the Action Research loops (Figure 12) which feed into the process. The Action Research loops may form many loops before feeding back into the design. The design of animal traps is made more complicated than the design of a product where you can talk to the end user. “A successful product design must combine natural creativity with the systematic use of structured design methodology and modern computer-aided design tools” (Kurowski & Knopf, 2006, p. 1).

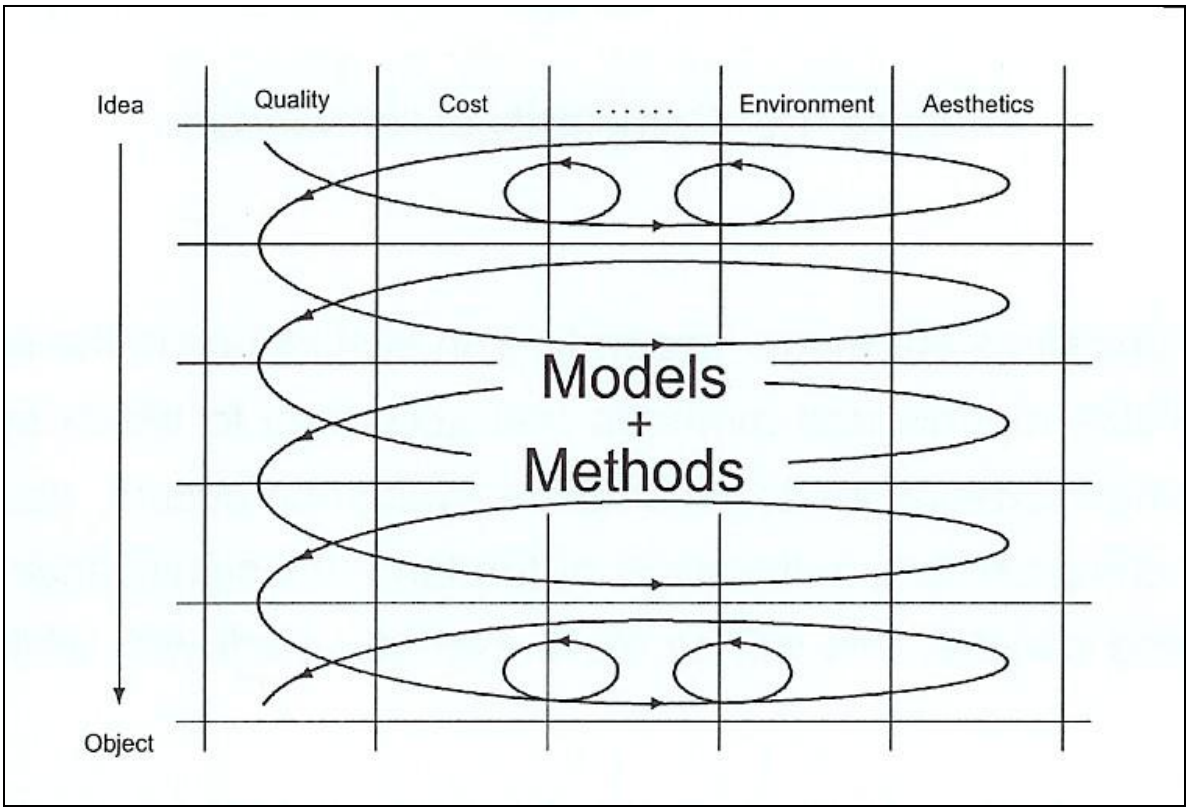


Figure 12. Design loops with Single Action Research loop (Rodolph, 1995)

The remainder of this thesis is built around this broad design approach.

3.3 Design approach

3.3.1 Action Research

Action Research is a concept developed by Lewin (1944) to describe a spiral of steps, each of which is composed of planning, action and fact-finding about the result of an action (Figure 13). Action Research provides a base methodology within a design methodology. It underpins the action part of the learning cycle.

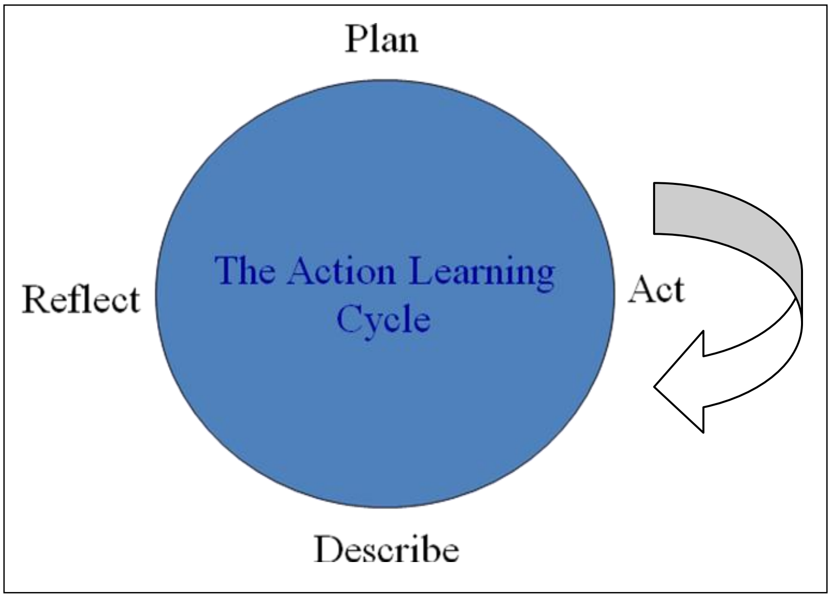


Figure 13. Action Research single loop learning cycle

There are numerous approaches to action research; however, Stringer (1996, p. xvi) notes that all of them:

- are rigorously empirical and reflective
- engage people as active participants in the research process
- result in some practical outcome.

Despite these common components, there is no one set approach in a multifaceted project like that undertaken in this thesis. “During the life of an action research project the approach may shift from one type to another as it moves through the spiral of cycles” (Hart & Bond, 1995, p. 46). The actual number of the subcategories of Action Research can seem ever-increasing and very fluid, but it does provide a base by which a sound methodology can be established.

The basic Action Research model of act-describe-reflect-plan places greater demands on those responsible for “action” in the research to be involved in the initial reflection process (Anon, 2004). In the early development of traps I found it difficult to be part of the reflection process.

However, as my knowledge increased over the course of thesis research I was better able to perform this function. This experience was also recognised by Dick (1998, p. 3):

> "Action research is emergent. It assures a clearer form and substance as it progresses. In the latter cycles, both the processes used and interpretation developed are shaped by the understanding in earlier cycles. Each step generates understanding which informs the steps which follow".

3.3.2 Cooperative Inquiry

In Cooperative Inquiry all active participants are fully involved in research discussions. As the research projects, which form the application of this thesis, are part funded by DOC their staff needed to be and were actively involved in the research.

Lewin (1958) developed a model for Action Research in organisational development (Figure 14). This model can easily be applied to DOC and their interest in obtaining a humane and cost-effective animal kill trap. Once these traps have been identified then Best Management Practices (BMP) are written. Allen et al. (2001, p. 217) notes that: "even when best management practices are drawn up, they are continually superseded because of changing ecological knowledge, legislation, social considerations, and land-use practices". Currently in New Zealand there is no legislative requirement for the NAWAC guidelines to be adopted.

If we want to change people's behaviour (for instance, to improve the effectiveness of current pest-management activities) then we face the difficult task of changing people's views. Lewin (1958), explains the process of change as involving three steps: unfreezing, changing, and refreezing as discussed in detail by Levasseur (2001, pp. 72-73):

- **Unfreezing**: Faced with a deterioration, a group becomes aware of the need for change (e.g., DOC becomes aware the traps they are using are inhumane)
- **Changing**: The situation is diagnosed and new modes of behaviour are explored and tested (e.g., DOC seeks new humane traps)
- **Refreezing**: Application of new behaviour is evaluated and, if reinforced, adopted (e.g., trap accepted and BMP for use written and adopted).

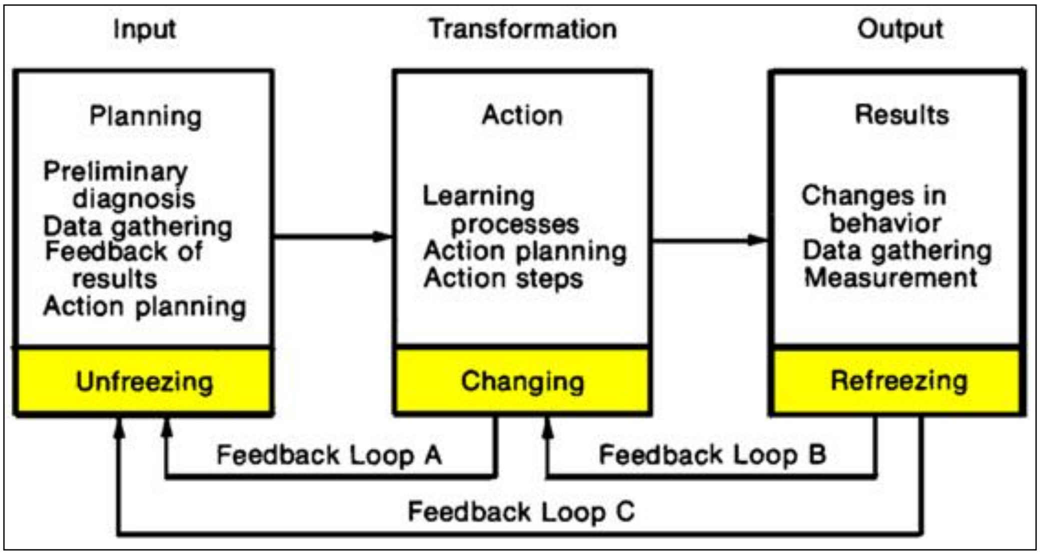


Figure 14. The steps and processes involved in Cooperative Inquiry (Lewin, 1958)

It will be very interesting to observe whether once a trap has entered the refreeze mode how feedback loops emerge, and if so, what would it then take for unfreezing to occur.

Compliance with the NAWAC guidelines for kill traps is currently voluntary. Accordingly, some Regional Councils and DOC are recommending traps that have both passed (classified as Class A or B) and traps that have failed (Class C), e.g., Timms (Auckland Regional Council), Fenns (Napier City Council) and Victor rat traps (Southland District Council). For pest management, Feedback Loop B in Figure 13 would apply when a current trap that has passed the NAWAC guidelines starts to fail over time, and the expected field life was not as long as first anticipated. This possibility is investigated in Chapter 13 of this thesis. An example of Feedback Loop A would be where current traps are not protecting the wildlife and yet have passed the NAWAC guidelines (Anon, 1999b). For Loop C this could be that animal welfare issues for pests are now not as important as the welfare for the protected animals, and consequently any method that kills the pest, humanely or not, is acceptable.

3.4 Design Philosophy

Integrated with the design methodology is the design philosophy of the researcher. The design philosophy is the individual's approach to design and can often be influenced by historical designs. As Alber & Rudolph (2002, p. 80) state: "The absence of prior knowledge for possible solution approaches seems to support creativity and innovation, since this forces the designers to find their own approach". The design skills include the ability to think on an abstract level, to identify critical parameters; and to question. The methodology, when applied simultaneously, enables the designer to be effective, efficient, and innovative (Karuppoor, 2003).

Schumpeter (1934) classifies innovations in two major categories: product innovation and process innovations. Product innovations comprise "…the creation of a new good which more adequately satisfies existing or previously satisfied needs" (Schumpeter, 1934, p. 134). Product innovations also include the creation of completely new products, and provide a monopoly position to the innovator. A process innovation replaces "…one production or consumption good by another, which serves the same or approximately the same purpose, but is cheaper" (Schumpeter, 1934, p. 134). According also to Schumpeter, process innovations include introducing new materials or supplies that have the potential of producing a unit of a product more cheaply.

The design philosophy will ultimately constrain the design process, e.g., a designer may only wish to use certain materials or types of connection systems. The degrees of novelty vary from minor, incremental improvements, to radical changes, to how a product is perceived or how an industrial process is conducted (Tidd et al., 2001). Figure 15 represents the two dimensions of innovation, different levels of novelty, and type of innovation.

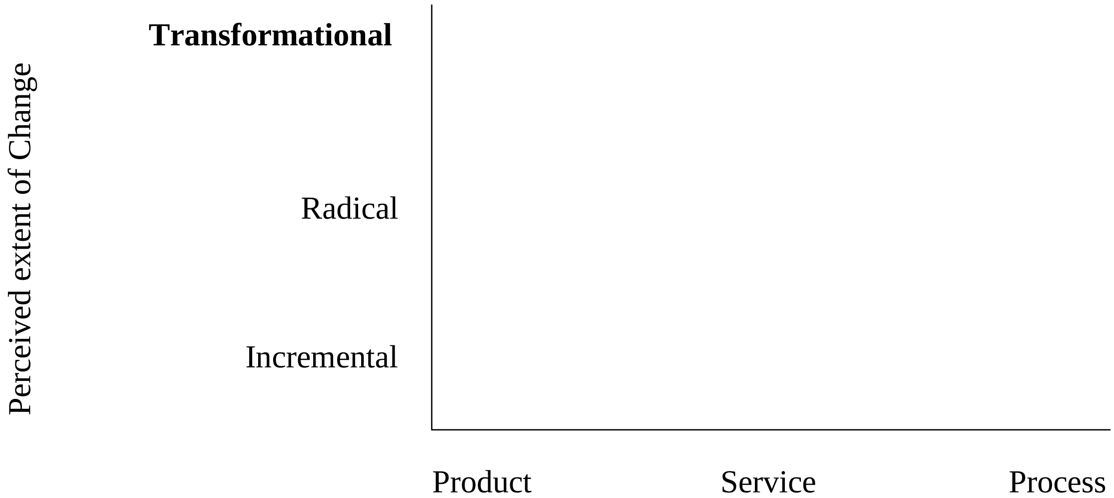


Figure 15. Dimensions of innovation space (Tidd et al., 2001)

The KISS ("Keep It Simple Stupid") principle to design is my key philosophy, so that unnecessary complexity is avoided. The theoretical physicist Albert Einstein outlined a similar philosophy, stating: "Everything should be made as simple as possible, but no simpler" (www.hppt://rescomp.stanford.edu/~chesire/EinsteinQuotes.html). Another philosophy embedded in my approach to design is the famous quote by French writer and aviator Antoine de Saint-Exupéry: "It seems that perfection is reached not when there is nothing left to add, but when there is nothing left to take away" (Wind, Sand and Stars, 1939, p. 1).

Both these philosophies are important, as when applied to design they ensure a design is reduced to its most basic functional form. The design process outlined in section 3.5 embraces these principles.

3.5 The Design Process

Invention is mostly recognised to trigger innovation, although some studies refer to "design" as the core of the innovation process (e.g., Freeman, 1982). The design process is a structured step-by-step process (Parsaei & Sullivan, 1993), with one result leading to the next.

The traditional view of the process from design to manufacture is that it is sequential, with the outcomes of one stage passed on to the next process (Ashley, 1990). The process is represented in Table 2.

Table 2. Overview of the Design Process (each box is detailed in the remainder of this chapter)

Design Philosophy	**Techniques & Methods**	**Design Methodologies**	**Design Stages & Outputs**
Critical parameter Identification (3.5.1)	Object Function Method (3.5.2)	Function Structure Development & Constraint Analysis (3.5.3)	Need Analysis: • Need Statement • Function Structure • Design Requirements (3.5.4)
	Concept Search Techniques (3.5.5)	Concept-Configuration Model, Concept -Generation & Selection (3.5.6)	Conceptual Design: • 3-Design Concepts • Selected Concept (3.5.7)
		Design Principles & optimization (3.5.8)	Embodiment Design • Design Layout (3.5.8)
		Manufacturing Design Principles (3.5.9)	Detailed-Design & Product creation • Engineering Drawings • Product Prototype • Patent (3.5.10)
			Comparative Evaluation (3.5.11-12)

This tends to lead to iteration in the design, i.e., having to go back to an earlier stage to perform corrections. This can make products expensive to develop, and extend time to marketplace. A potentially better approach is for the designer to consider the implementation stages following design to try to eliminate any potential problems. Customer feedback on how the product is perceived is also critical in determining the appropriate level of technology to put into the product (Barr, 1990). The importance of having honest input from practitioners in the field is incorporated into the design methodology.

Each component of the design process (Table 2) is explained in this thesis (sections 3.5.1-3.5.12). The design process operates from left to right following sequentially through the numbering system. Some components become redundant when a new product is being developed, and this is fully explained in the following sections.

3.5.1 Critical Parameter Identification

Critical parameters look at the broad purpose of the design, and look beyond the details of any single component. Meetings were held with DOC staff to determine critical parameters. They began with open-ended questions to end-users and animal ecologists. This is a technique identified by Hughes (2000, p. 1):

> "Some action research projects start off with fuzzy questions. The first action research cycle may provide fuzzy answers to lead to less fuzzy questions, less fuzzy answers and so on, until later cycles are able to provide precise answers to specific questions."

The critical parameters (Montabert, 2006) will then be identified. This process can also be called abstraction. It ensures that the design does not become constrained with detail that could be detrimental to the innovative process.

3.5.2 Object Function Method

The object function method looks at the interactions of one object in a design with another, to identify the interactions between components. This method gives the designer an indication of the number of components involved. It is usually used in modifying an existing design. There is no hierarchy placed on the objects (parts of trap). Instead, the method shows linkages from one object relative to another (Figure 16). The object diagram will show which object, if any, is the keystone for the design. It also shows if an object can be made redundant, as there would be no linkages to the object. The method gives the designer a good understanding of the interactions between components in the design. If a new product is being developed, the function method and function structure development are redundant.

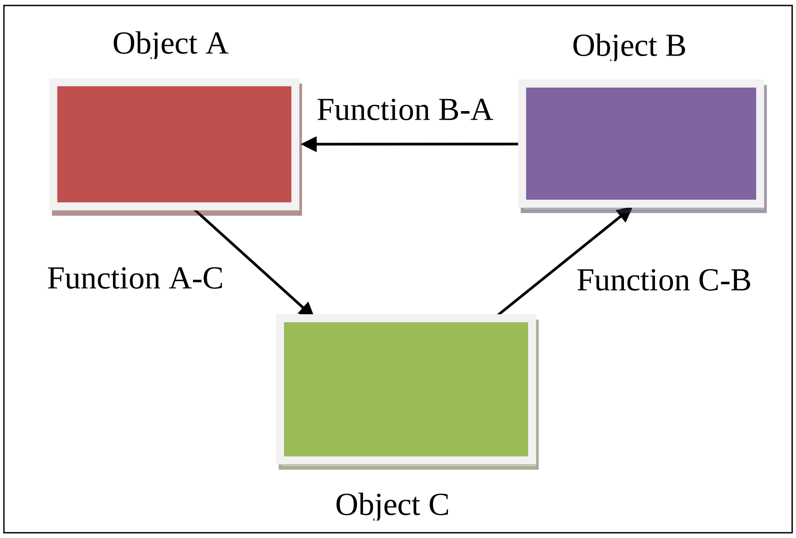


Figure 16. Object function relationship diagram

If there are dual functions between objects then a primary and secondary function need to be defined.

3.5.3 Function Structure Development and Constraint Analysis

There may be limitations or constraints that prevent an object from being removed; or it may be imperative for the operation that the linkages remain for the operation of the other objects, e.g., the wheel nuts that hold a car rim on. The wheel nuts are obviously imperative to the design. Normally the function structure development and constraint analysis is used to improve or modify an existing design.

3.5.4 Need Analysis and Design Requirements

The need statement reflects what we are trying to achieve in the design. This statement should be short and explicit, and can be applied to both a new product and an existing product. As Moran & Carroll (1996, p. 1) state: "Defining the problem is as much part of design as defining the artefact". The design requirements may be those requirements that the design *must* satisfy to be considered as a realistic solution, or requirements that the design *may* satisfy.

3.5.5 Concept Search Techniques

Much time and thought is needed for this phase, as the selection of the broad approach for the design is based on this decision. Existing product evaluations, patent searches, literature searches and discussions are usually required. Evaluation of existing products is well recognised as a means of aiding design. As Ward et al. (1995, p. 44) state: "Designers are historically aware they borrow from other designs". The use of patent searches has been formulated into a research technique: the Russian equivalent of the Theory of Inventive Problem Solving (TRIZ) (Smith, 2003, p. 1), which uses a system of looking at patents. Both approaches are used in this thesis.

3.5.6 Concept Configuration Model

The concept configuration model demonstrates a method by which input of the "need" into a concept space will create ideas based on the need (Figure 17). The concept space will be focused by the results of the concept search technique. The filter is then made up of the output from the design requirement from the need analysis. The concepts are filtered until a successful design makes it through to the configuration space. By slightly changing the need, a possible solution could be achieved which may give an indication of where an acceptable concept may lie. The design then progresses to a concept evaluation stage. Usually at least three designs are selected.

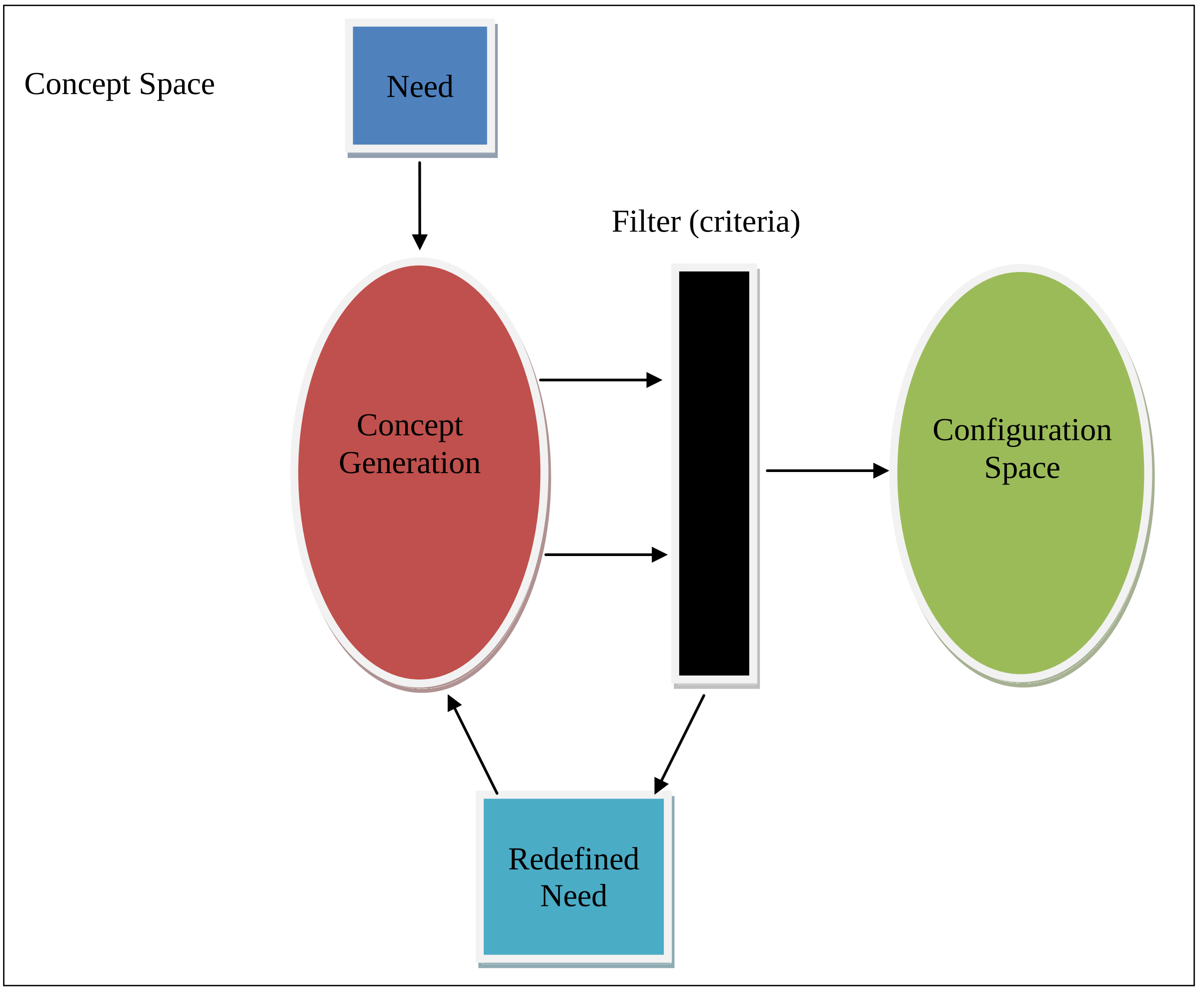


Figure 17. Classic concept configuration model

It is imperative that a "solution" is produced which reflects a true understanding of the actual problem. The solution is aided by input from the Cooperative Inquiry cycle.

3.5.7 Concept Design

The importance of this phase when designing a product is to not only consider the product design specifications, but also to consider the activities beyond the design stage. Downstream activities typically are manufacturing, sales and transport. This stage is about drawing up a number of viable concept designs which satisfy the product design specification. Therefore, this is a two-stage process of concept generation and concept evaluation. A useful technique for design evaluation is matrix evaluation (Ali & Falkenburg, 1999). With matrix evaluation a table is produced listing important features required from a product. Usually this list is developed from the important features described in the product design specification. The first concept is the benchmark concept. The other concepts are then compared against the benchmark concept for the required features (criteria), to help evaluate whether the concept is better (+), worse (-), or the same (0) as the benchmark concept. As shown in Table 3 below, in a simplistic demonstration, the values for the concepts are summed, and the design with the higher rating developed further, i.e., concept 2.

Table 3. Generic Concept Design Criteria Evaluation Table

	Concept		
Design Criteria	**1**	**2**	**3**
A	+	-	**D**
B	+	+	**A**
C	**0**	+	**T**
D	-	+	**U** **M**
Total	**1**	**2**	**0**

3.5.8 Design Principles, Optimisation and Design Layout

At this stage of the design process, engineering analytical design (Shigley et al., 2003) is applied to determine the loads, relative size and material selection based on life in a corrosive environment. The methodology used for this thesis is to produce 3D models using SolidWorks® (modelling/analysis software) and then to seek comment from interested parties. The computer generated model also ensures that there will be little error in the physical size of components chosen, so that mechanical clashes do not occur. One critical parameter is that there is less than NZ$20 available to create the manufactured product, as this is approximately the cost of a single Fenn trap. The cost is based on the assumption that the new humane trap will catch at the same efficacy as the Fenn Trap; however, if a trap caught at a higher efficacy a higher cost may be justified. The Trap Factor developed in section 3.5.12 provides a methodology for trap comparison. The low target trap cost means that very creative design is required to achieve this constraint. There is little opportunity to create components that will need specialised tooling to develop, as the production runs will be small. This component design phase is normally recognised as a high time input area (Figure 18). The time requirement will be even higher because of the need to develop traps that will not need specialised tooling. The pre-deployment and deployment stages that take place during the commercialisation phase and the design methodology presented will follow the integrated approach. However, the exact process will ultimately depend upon the commercialising company. The “KISS” design philosophy will help to ensure that as few parts as possible are used, thus single parts will need to perform multiple functions.

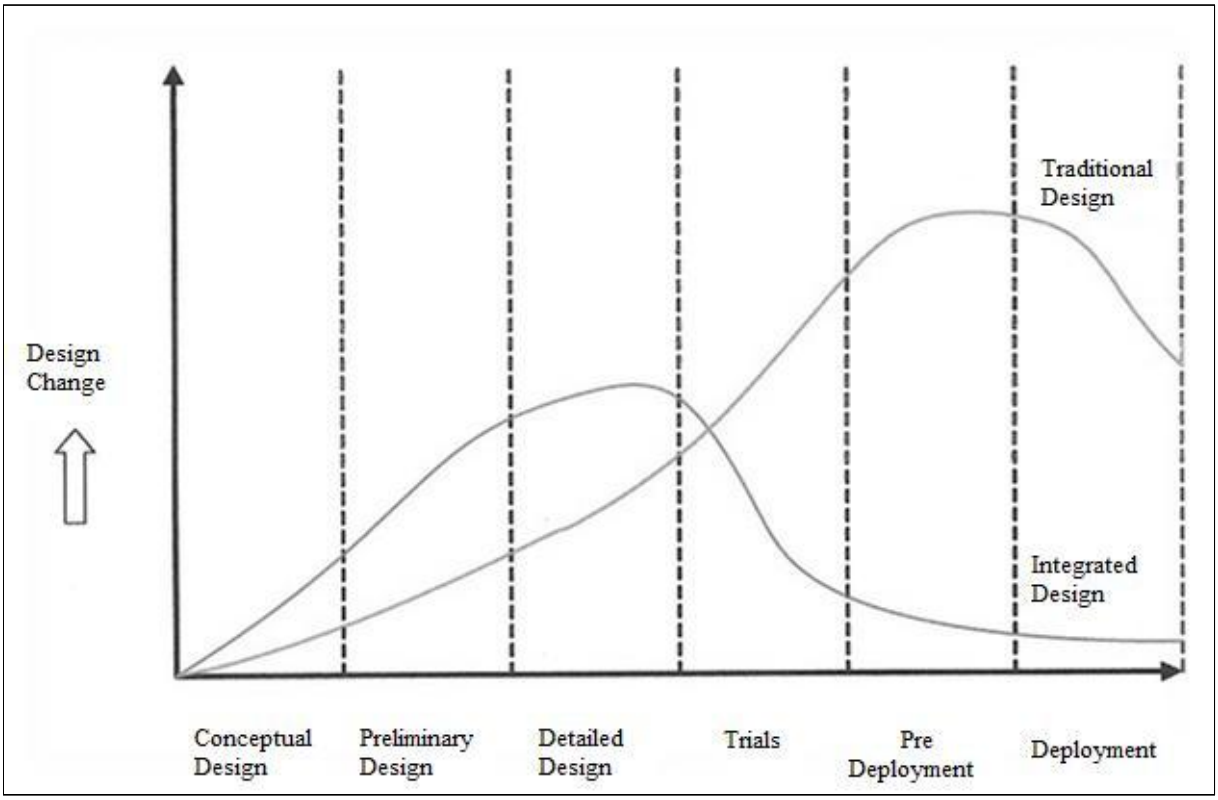


Figure 18. Relative time input required in the design process (Rodolph, 1995)

3.5.9 Manufacturing Design Principles

A CNC (computer numerically controlled) Turret Punch will be the main tool used in manufacture. CNC machines can manufacture complex parts at a relatively low cost without the need for specialised tooling. However, there are limitations on the metal thickness (3 mm) due to the local availability of machines. Also, the manufacturing needs to be completed at one location due to the cost of moving components from manufacturer to manufacturer. Therefore, the selection of manufacturer will also be important.

3.5.10 Detailed Design and Product Creation

3.5.10.1 Engineering Drawings

The engineering drawings are developed directly from the 3D model in the SolidWorks® programme. The plans allow for a sheet metal component to be flattened, with all bending radius accounted for in the flattened form.

3.5.10.2 Prototype

Before field testing, the eventual prototype will first need to be evaluated against NAWAC guidelines (Anon, 2000). Also, under NAWAC guidelines, the trap must be commercially available. There are many options for the number of animals that need to be tested. The higher the number tested, the higher the chance a trap may have of fulfilling NAWAC's criteria.

3.5.10.3 Patent

To ensure that the intellectual property (IP) is protected, any potential design will have provisional patent protection, which gives up to 18 months of protection before the need to file a full patent application (www.nzpatentoffice.co.nz). The decision on the need for subsequent IP protection will be made after pen testing. Pen testing of traps is conducted under conditions as prescribed by NAWAC guidelines. If the trap achieves a pass classification under NAWAC guidelines then IP protection will be considered.

3.5.11 Trap Evaluation

Ultimately the animals will be the main indicators of whether a trap is effective or not. NAWAC requires field trials, and the trap should meet criteria on performance, labelling and end-user safety. The traps' eventual release to end-users will again provide a feedback loop.

3.5.12 Trap Comparison and the "Trap Factor"

There is currently no overall framework for comparative trap evaluation (i.e., Trap A versus Trap B). Accordingly a "Trap Factor" evaluation system based on trap selectivity, humaneness, trap placement (deployment), efficiency, annual cost and ease of use has been developed. First, each of the proposed variables comprising the "Trap Factor" is established from a review of the literature. Second, each variable is discussed and an explanation given of how the numerical value is to be calculated or assigned. Third, in chapter 6, the proposed Trap

Factor methodology is applied to the traps developed as part of this thesis and applied to other researchers' data to evaluate other traps in a holistic way. Fourth, in chapter 14, the Trap Factor is applied to trapping systems (leg-hold and snare) to investigate if the Trap Factor can identify areas which trap designers should focus on.

The selection of the criteria for the Trap Factor is reinforced in trap literature. Shivik et al. (2000, 2005), Fleming et al. (1998) and Hubert et al. (1996) all suggest that three aspects of trap performance be considered when selecting traps: humaneness, capture efficiency and trap selectivity. Much of the literature concentrates on evaluation of injuries and the capture rate in the field (e.g., Darlow et al., 2008; Woodman et al., 2008; Munoz-Igualada et al., 2008; Blundell et al., 1999), with others considering the cost implications of purchasing various traps (e.g., Austin et al., 2004; Hourigan et al., 2008; Parkes & Murphy, 2004; Brown, 2003). The ongoing maintenance of cleaning has also been considered (e.g., Vice et al., 2005; Brown, 2003) with others also including the cost of deployment (e.g., Hourigan et al., 2008). Because the trapper's skill level can vary the ease of use (e.g., Hubert et al., 1996) it also is a factor that needs to be considered.

The above literature does not weight one variable above the next (when multiple variables are proposed to be considered) nor imply that the relationship between variables should be non-linear. For these reasons it is proposed that the "Trap Factor" be a linear equation comprising of all the factors identified and be given by:

Trap Factor= Selectivity*humaneness*placement*efficiency*annual cost*ease of use

The higher the trap factor, the better the trap is. The trap factor would allow the comparison of two traps used in a trial to determine which trap has the highest trap factor and ultimately which "performs" to a higher level.
Each of the inputs is discussed below with an explanation of the numerical value assigned to each criterion and the source or means of calculating the numerical input.

<u>Selectivity:</u>

In the New Zealand situation, selectivity is usually dealt with by providing a tunnel (Parkes & Murphy, 2004) or by positioning the traps at a height to exclude non-target animals (Thomas et al., 1999). Traps (e.g., DOC 150) will capture multiple pest species (www.predatortraps.co.nz) and the catching of any pest species, e.g., rat, stoat, hedgehog, ferret or weasel, is considered a successful catch, however, precautions need to be taken when endangered native lizards are present (Meens, 2010).

Because of the social concerns about accidentally trapping birds (e.g., kiwi) a high degree of protection for birds is provided via the trap cover or trap placement. Furthermore, for a trap to be acceptable to DOC it must specifically prevent native birds from being caught, either by choice of bait type (Brown et al., 2002), covers or physical placement.

There are situations where a preference to catch one pest species over another is paramount, e.g., when targeting ferrets for TB control. This situation should be dealt with in the efficiency aspect of the trap factor as a trap that is more sensitive to capturing a single target species may be preferential.

Based upon the above selectivity, values range from:

0 = trap catches an unacceptable number of non targets

1.0 = trap captures target species and an acceptable number of non target.

The issue of being acceptable or non acceptable is going to be influenced by the conservation value of the protected species, e.g., kakapo (unacceptable zero tolerance) to weka (possible acceptance depending upon location). The actual determination of an acceptable killing level of a native species would need to be determined by its conservation value and location, e.g., weka are legally able to be killed on the Chatham Islands.

<u>Humaneness:</u>

Humaneness is based upon whether the trap has passed the NAWAC trap guidelines. There are four class levels (Anon, 1999b), Class A, Class B, Class C and prohibited. If either of the criteria of sensitivity and humaneness has a zero value then the Trap Factor equation will ultimately have a 0 value irrespective of the other inputs. Based on the above, the humaneness values range from:

1.0 = passed NAWAC guidelines (Class A)

0.75 = passed NAWAC guidelines (Class B)

0.5 = not tested

0.25 = failed to meet NAWAC guidelines (class C)

0 = prohibited trap

The reason for the numerical variation between Class A and Class B (Anon, 1999b) is that Class A has a higher humaneness level.

<u>Placement:</u>

Placement is measured by comparing the number of traps that are able to be carried by a single person. If the traps were located along a road the placement factor would become less significant and would be given a unity value.

For calculating the number of traps that can be carried either trap weight or volume will be the dominating factor. It is assumed that a person can carry 20 kg and a pack volume of 75 l. There are two calculations that need to be made for each individual trap to determine the maximum number of traps that can be carried or fit into the 75 l pack. The lower number based on these two criteria is then used to compare one trap against the other.

Placement is measured by first, calculating the minimum number of traps able to be carried (based on the weight and volume criteria) and second, comparing the number of traps that can be carried against the combined total number of the two traps being compared.

a) Number of traps that can be carried in a 20 kg pack = 20 kg / (trap weight kg)

b) Number of traps that can fit into a 75 l pack = 75 l / (trap volume l)

The minimum number from the calculation from a & b is used to determine the trap placement factor for each of the two traps being compared.

Trap A = minimum number of trap A able to be carried

Trap B = minimum number of trap B able to be carried

Trap Placement (Trap A) = Trap A / (Trap A + Trap B)

Trap Placement (Trap B) = Trap B / (Trap A + Trap B)

Efficiency:

Efficiency is measured by comparing the catch rate of two traps, e.g., Trap A and Trap B. This measurement requires field work evaluation to take place and is usually conducted after the passing of the NAWAC guidelines.
Efficiency factor (Trap A) = (Number of target pests caught for Trap A) / (Total number of target pests caught for both Trap A and Trap B).

Annual cost:

Annual cost factor Trap A = 1 - (cost Trap A / (cost Trap A + cost Trap B)).
This is calculated as a yearly cost over the life of the trap. This does not take into account the time value of money, as a Net Present Value (NPV) type of approach would.

The annual cost factor requires an assumption to be made on the life of a trap, which is dependent upon trap materials, maintenance and location. The evaluation of trap life is difficult for new traps as there is usually no data regarding longevity in the field. An assumption will need to be done based on trap materials and it is proposed to be in 5 year increments, i.e., 5, 10, 15.... years.

Ease of Use:

The ease of use is a subjective measurement and relates to the difficulty in setting, baiting and clearing the trap. This value also relates to the end user and the physical limitations, e.g., volunteers using the trap. The Timms trap is easy to set, clear and bait (Warburton & Orchard, 1996) and for these reasons is used for comparing the developed traps against.

Ease of use factor = (ease of use of tested trap) / (ease of use for Timms Trap)

The Timms trap set as the maximum =1.0

1.0= trap is equivalent to Timms trap

Various degrees between

0 = trap is impossible to use.

3.6 Trap Static Clamp Measurement

To measure the static clamping force of traps it is necessary to measure the static clamp when the trap is closing. This is because when a trap opens there may be components that slide better on opening than closing, e.g., the locking arms on Victor leg-hold traps. The traps are measured at either 10mm or 20mm opening as these openings are representative of the static clamp positions for stoats and possums (B. Warburton, pers. comm., 2002). The trial is to measure the static clamp of the DOC 200 stoat trap; therefore, a static clamp distance of 10mm is used.

The procedure used was similar to Warburton et al. (2002), for measuring the static clamp at 10mm opening for a Victor rat trap. The major difference being the static clamp was measured in the laboratory situation using a tensile tester as opposed to using a digital scale. The equipment used and the procedure is:

Equipment

Digital scale: Senior 0CS-20B

10mm go-no-go gauge

Wax paper and pen

Procedure

Step 1: Trigger trap

Step 2: Connect scale hook to top jaw and pull to past 20mm opening

Step 3: Using go - no - go gauge let the trap jaw lower to 10mm

Step 4: Hold scale until it beeps showing that load has normalised for 5 seconds

Step 5: Record date, trap number and load

3.7 Data Analysis

This section details the statistics used in this thesis starting with an explanation of the null hypothesis, power analysis, *t*-test and correlation coefficient. Ecologists yearn for exact data but nature does not normally cooperate and large sample sizes and statistics are required to robustly test the null hypothesis (see section 3.7.1). Some researchers call this "physics envy" (Egler, 1986) as physicists often do not need large sample sizes, as often variation in data is typically due to instrumentation error, which is usually minor. The challenge of trap testing is that we are totally reliant on catching animals, which could be influenced by; trap placement, bait used, trap materials, animal being trap adverse, season and animals presence in the trapping area (Dilks, 1996). For trap testing these result in either, a very large number of traps being used or the study being repeated over many seasons in an attempt to catch enough animals so that a robust statistical test can be obtained. Scheiner & Gurevitch (1993, p. 9) state, "There are many right ways to use statistics. On the other hand there are many wrong ways". Consequently, as part of this thesis outside expert help was sought from DOC and Lincoln University staff to design the field trials and conduct the statistical analysis.

To ensure that there was a clear distinction between the developer and the evaluator of the traps (developed as part of this thesis), all field trials were managed by DOC staff. The choice of number of traps, trap spacing, trap placement, data gathering and statistical analysis was conducted by DOC field staff and biometricians. In hindsight this was a mistake as I did not foresee the problems of changes to staff that were monitoring the traps, trap placement issues, actual trial location and limited access to the raw data (see Chapter 4.12 for discussion of these issues).

3.7.1 Null Hypothesis (H_0)

An example of a null hypothesis is: that on average, the average catch rate of stoats between two different trap designs is equal.

H_o: $\mu_{trap\ 1} = \mu_{trap\ 2}$

Where:

$\mu_{trap\ i}$ – average catch rate of trap *i*

By using statistics we can help test the null Hypothesis and the students *t*-test (two tailed) is the most commonly used test to reject the null hypothesis, when there are two independent samples. Rejection of the null hypothesis will occur at a probability level of $p<0.05$. Scheiner & Gurevitch (1993, p. 9) state: "Somewhere along the line, a value of $p<0.05$ becomes a magic number", however, it is an attempt to minimise the possibility of a Type I error (see below). A central assumption in using a *t*-test is that the data approximately fits a normal distribution (bell–shaped or Gaussian curves).

3.7.2 Power Analysis

Power analysis (Cohen, 1992; Gerrodette, 1987) is used to determine the smallest sample size that is suitable to detect the effect of a given size at the desired level of significance. Generally, the larger the sample size the easier it is for the researcher to achieve the $p<0.05$ level of statistical significance (Cohen, 1994).

There are two types of errors the researcher can commit: Type I error and Type II errors. Statistical power mainly deals with Type II errors. Type I error, also known as an "error of the first kind", an α error, or a "false positive": the error of rejecting a null hypothesis when it should not have been. An example of this would be if a test shows that a woman is pregnant when in reality she is not. Type I error can be viewed as the error of excessive credulity. In other words, a Type I error indicates "A Positive Assumption is False" and is considered the worst error.

Type II error, also known as an "error of the second kind", a β error, or a "false negative": the error of failing to reject a null hypothesis when it is in fact not true. In other words, this is the error of failing to observe a difference when in truth there is one, thus indicating a test of *poor* *sensitivity*. An example of this would be if a test shows that a woman is not pregnant, when in reality, she is. Type II error can be viewed as the error of excessive scepticism. In other words, a Type II error indicates "a negative assumption is false".

The power analysis therefore gives an indication of the number of animals required to be sampled to reject the null hypothesis. The power level of 0.90, will mean that there is 90% probability the researcher will not commit a type II error (i.e., the test has a 90% chance of detecting a difference when one exixts).

3.7.3 Test of Two Means

There are many ways to test the null hypothesis: H_o: $\mu_{trap\ 1} = \mu_{trap\ 2,}$ but the most widespread is the *t*-test for continuous data. The calculation is from the following equation:

$$t = abs(\bar{x}_1 - \bar{x}_2)/((s^2_1/n_1 + s^2_2/n_2))^{0.5}$$

Where:

t = *t* test value

$\bar{x}_{i\ =}$ mean of sample i

s_i = standard deviation of sample i

n_i = number in sample i

If the means are similar then the value of *t* will be close to zero and large if the means are different. To determine whether the difference is significant, you need the “degrees of freedom” (d.f.), which is given by $n_1 + n_2 – 2$. The *t* table is looked up and the critical value of *t* for $p = 0.05$ and the appropriate degree of freedom.

3.7.4 Correlation Coefficient

The correlation coefficient tests the strength of the relationship between two continuous variables. By using the Excel programme a goodness of fit “r” value is obtained between -1 to 1. A high correlation coefficient (i.e., close to 1) represents a good level of fit. The coefficient of determination, r^2 is used in the context of statistical models whose main purpose is the prediction of future outcomes on the basis of other related information and is simply the square of the correlation coefficient. A p-value can also be obtained to determine whether the slope (B_1) of the linear line is significantly different to zero, i.e., there is no relationship.

3.7.5 Sensitivity Analysis

Pannell (1997, p. 142) states: "In principle, sensitivity analysis is a simple idea: change the model and observe its behaviour". The researcher usually decides to vary parameters one at a time, while leaving all other variables constant. A common approach is to specify values in advance, usually with equal sized increments (Nordblom et al., 1994). When conducting sensitivity analysis a great deal of data can be generated (Eschenbach and McKeague, 1989), e.g., a complete sensitivity analysis of the Trap Factor equation, using 0.1 increments for the variables of selectivity, placement, efficiency, annual cost, ease of use and five input values for humaneness would result in 500,000 different combinations.

3.7.6 Application of Statistical Methods in Thesis

To ensure complete impartiality between designer and evaluator, all bar one of the field trials in this thesis were designed, conducted and analyzed by DOC staff.

Sections 3.7.1 to 3.7.5 identified the specific research methods I used in this thesis. In summary:

- in chapter 6 sensitivity analysis is used in the evaluation of the Trap Factor for the comparison of two traps
- in chapter 13 sensitivity analysis is used in the evaluation of the Trap Factor for the evaluation of two trapping systems
- in chapter 14 the correlation coefficient is used for the comparison of two continuous variables, time and static clamp for a DOC 200 trap
- in Appendix A the null hypothesis, power series and test of two means was used.

The above statistical analysis of the two field trials (Chapter 14 and Appendix A) was performed with the aid of Lincoln University staff (Dr. G. Kerr and Dr. J. Ross).

3.8 Methodology Conclusions

In this chapter I have shown a clear distinction between inventive (Eureka type moments) and innovative design processes that follow accepted academic methodology. The Trap Factor equation allows for a holistic comparison of two traps as opposed to looking at catch rates which is demonstrated in chapter 6 and the conclusions chapter 15.

In the next chapters, 4-12 of this thesis, I shall demonstrate understanding and knowledge developed in the cycles of Action Research by designing traps targeting stoats, ferrets and possums; and ultimately a trap that targets all pests. I shall then demonstrate an improved methodology, learnt in the course of this thesis, with a concept rat trap taken as a design example.

Chapter 4

Design 1: Stoats – Development and Evaluation of "Thumper"

4.1 Introduction

In 2000, the Government targeted $1.6 million to a stoat research programme to be completed within five years. A group of DOC scientists (STAG: the Stoat Advisory Group) administered the fund and helped direct research (Murphy & Fechney, 2003). STAG had a three-pronged approach for stoat control: being biological controls, poisons, and traps. The objective of my research was to develop a stoat kill trap within the ambit of the overall stoat research programme that would meet NAWAC's Class A or B ranking. The design process as outlined in chapter 3 was followed.

4.2 Need Analysis

The major reason why new traps are needed is because the current trap, Fenn Mk 6 failed to achieve Class A or B rankings under NAWAC guidelines (E. Murphy, pers. comm., 2003).

Need Statement: *To design a simple kill trap that is classified as Class A or B as outlined by the NAWAC guidelines.*

4.3 Design Requirements

A Cooperative Inquiry approach was used to determine what the end-users required of a stoat trap. Focus group meetings were held with DOC Dunedin and Christchurch staff and the STAG advisory group committee members, to determine what their requirements would be for the 'ideal' stoat trap. The feedback from these meetings guided the selection of the design criteria, which are listed in section 4.4.

4.4 Design Criteria

Meetings were held with the STAG group and DOC focus groups to determine what they considered the main design criteria for a stoat trap to be:

- Light weight - (<1kg) – equivalent to Fenn 6 plus plastic cover
- Humane - able to pass NAWAC guidelines
- Low-maintenance - able to be repaired and assembled in the field
- Effective - with a high catch rate equivalent to or better than Fenn traps
- Easy to use - both for commercial trappers and laypeople
- Self-contained - with an integral cover
- Stoat-specific - catching stoats only and excluding non-target animals, e.g., rats
- Low-cost (retail < $20).

4.5 Concept Search Techniques

The major trap used for stoat control is the Fenn, and to a lesser extent the Victor 1.5 Professional, both of which are ranked as Class C traps for stoats under NAWAC guidelines (B. Warburton, pers. comm., 2004). Modified rat traps passed the Canadian welfare test to kill weasels, and were tested on stoats by Warburton et al. (2002). My input into this testing was to evaluate the mechanical properties of a rat trap. The rat trap failed to pass the NAWAC guidelines because a stoat struck by the trap managed to escape. This rat trap provided a threshold value, which trap designs need to exceed to pass the NAWAC guidelines.

The United States patent index (http://www.uspto.gov/patents/process/search/) was searched for rat traps as according to Warburton et al. (2002, p.11) “The results of this trial and the Canadian approval suggests that a Snapback trap with increased impact momentum and sufficient impact momentum and sufficient clamping force to hold the animal could effectively kill New Zealand stoats”. A file search covering the period from 1930 to 2004 revealed 324 patented rat trap designs. Many early rat traps were attempts at live multi-catch systems. These were not investigated further as they would not meet NAWAC guidelines. The remaining traps were classified according to trigger system and their ability to operate with a lure or bait. The reason for this was other researchers on the DOC-funded project were working on artificial lures (Murphy & Fechney, 2003) that will attract stoats to the trap from long distances (E. Murphy, pers. comm., 2004). A lure may be artificial and, unlike bait, may not be intended to be eaten. An example lure is aniseed oil, which can be used to attract possums (Aldwell et al., 2004). Consequently, the triggering system for these lures was not intended to be eaten, which meant that a bait removal or bait on the trigger system could fail.

A review of traps on the New Zealand commercial market indicated the most popular kill trap is the Timms trap for possums (Figure 19). In my opinion the Timms trap is popular because:

- it has a self-setting trigger
- it features a user-friendly pull on string-setting system
- there is no need to touch a dead animal when clearing the trap.

Figure 19. Timms possum trap (courtesy Manaakai Whenua Landcare Research Ltd)

However, although popular, the Timms trap has failed to meet NAWAC's Class A and Class B guidelines (B. Warburton, pers. comm., 2003) because during testing a possum escaped from the trap.

4.6 Concept Configuration

The proposed trap was based on the advantages listed above for the Timms trap, as a concept filter. Also there is a natural desire for stoats to run through tunnels (Brown, 2001). Much time was thus spent on this phase of the design process, i.e., around see-through traps. Many concepts were developed in the concept space but were filtered by the design criteria (4.4), along with wanting to maintain the advantages of a Timms trap (listed above).

4.7 Concept Design

The base concept for this design (Figure 20) was constrained in that the design was based on an over centred spring (a). The advantage of this system is that the spring will set automatically once it is moved over the centre position. This spring system is used in the Timms trap. The concept trap needs to be as small as possible and this leads to the block layout as shown in Figure 20. The spring needs to be connected to a fixed end (b) and stretched to the impact bar (c) whose motion is restrained by the impact stop position (d). Once triggered from the over centre position the spring wants to shorten and powers the impact bar until the stop position.

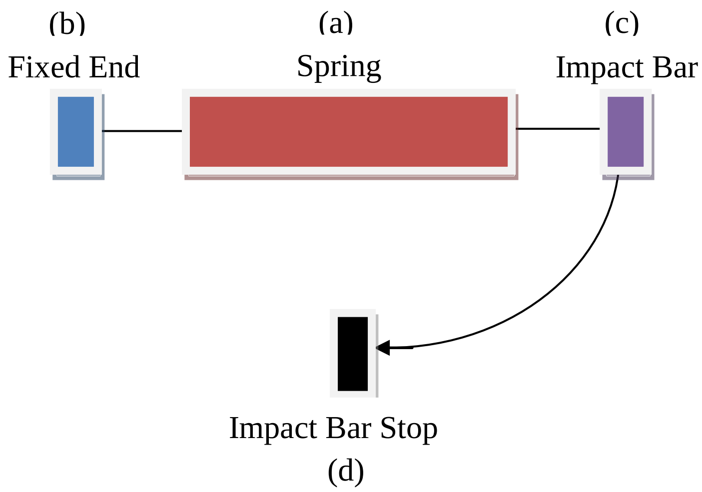


Figure 20. Block diagram for concept design

A frame is needed about the block diagram as shown in Figure 21.

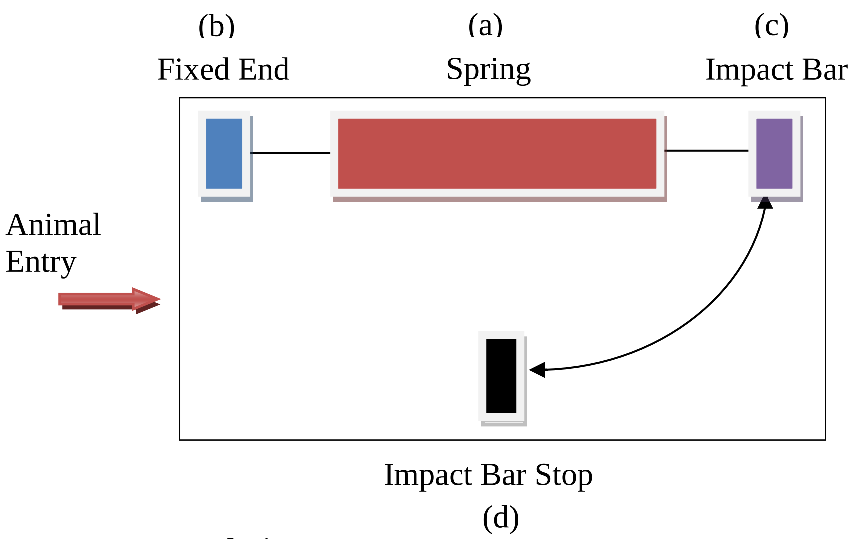


Figure 21. Concept design

Three concept designs were proposed as a triggering system to move the impact bar (c) from its over-centre position, thereby causing the impact bar to swing until it strikes the impact bar stop (d):

- Push trigger
- Pull trigger
- Treadle trigger.

Selected concept

As part of the Cooperative Inquiry with end-users, a concept trap (Figure 22) was taken to a DOC focus group for comment. It was agreed by consensus that the trap would use a push trigger. The justification for this is that stoats are small animals that spend much of their time investigating holes and pushing their way through undergrowth (Simms & Craig, 1998).

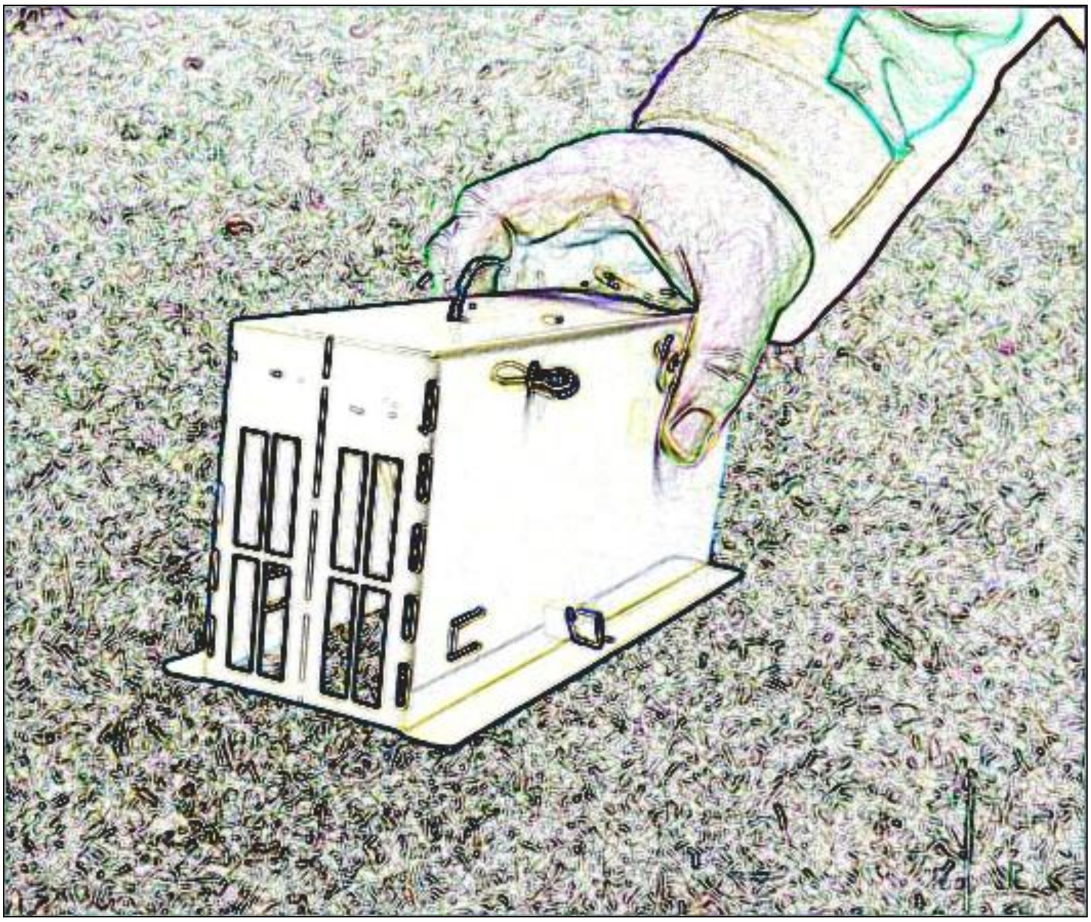
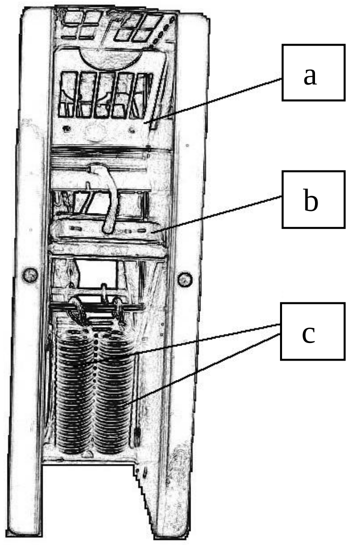


Figure 22. Conceptual sketch of the Thumper trap

4.8 Design Principles and Optimisation

The trap has a tension spring and was designed so that the coils do not touch when the trap is closed, thus preventing coils rusting together (Figure 23). The spring rate was 12 kg/cm, which with two springs (‘c’ in Figure 23) provided a clamping force in the closed position of 18 kg. In contrast, a typical rat trap has a clamping force of 0.8 kg. The impact bar (b) was made of 3 x 13 mm galvanised steel. The impact stress delivered to the stoat is directly influenced by the thickness of the bar. The thinner the bar, the higher the impact stress. The trigger (a) is made from a 3 mm stainless steel rod that has been bent in a cross shape to ensure that no welding is required. The body of the trap is made of 1.2 mm galvanised sheet, bent to form a top hat section (Figure 23).



(a) Trigger

(b) Impact Bar

(c) Springs

Figure 23. Design layout of concept trap

4.9 Manufacturing Design Principles

The manufacturing design principles outlined in the methodology (3.5.8) were followed with the selected concept. The form of manufacturing was constraining the concept design, as predicted in the methodology. The manufactured cost of the proposed trap was $10 which would meet the financial target for a retail cost of $20 (see section 4.4).

4.10 Engineering Drawings

The trap was modelled in SolidWorks®. From this programme the drawings were developed and the computer code directly downloaded to the CNC turret punches to manufacture the body and components (trigger plate, spring retainers, impact bar and impact bar stop).

4.11 Prototype

The prototype Thumper trap (Figure 24) was supplied to user groups for comment, with 20 traps manufactured and sent to government agencies, the Royal Forest and Bird Protection Society and landcare groups for feedback. The main points addressed in the feedback concerned:

- The need for a higher degree of rust protection for trap components (*stainless steel used).*
- Suggestions regarding making the trap in a double configuration to catch more than one animal *(double configuration manufactured)*.
- Impact bar strike location 30-40 mm behind nose *(strike location adjusted by trigger position)*.

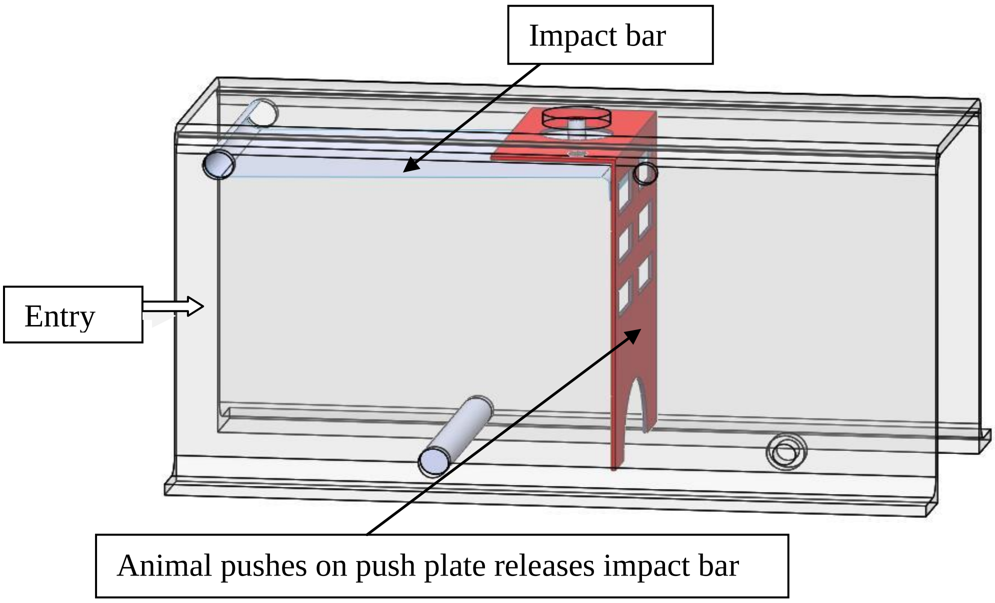


Figure 24. Single Thumper trap, showing trap in set position

4.12 Trap (Thumper) Evaluation

Thirty Thumper traps were manufactured and delivered to the DOC Hanmer (North Canterbury) office to trial against the current Fenn traps currently in use. Thumper traps were placed between existing Fenn (n = 30) traps at 200m spacing and baited with eggs. The prototype traps caught six stoats compared to the eight caught by the Fenn traps. Problems with the trigger system were identified with this trial. Rather than using a wire trigger, a shelled out trigger plate was used. It was decided to extend the trial, with the modified Thumper trap tested against both the Fenn and the newly developed DOC 180 trap (www.predatortraps.com).

The trial funded by DOC involved 380 traps. The trial had many monitoring difficulties, as the traps were located in both the North and South islands (generally located in remote locations). The initial trial showed a problem that required the push trigger plate to be changed. To maintain the trial's credibility, I had to physically replace all the treadles with a newly-designed wire trigger. Also, about 100 of the traps were found to have a design fault, and these were removed from the bush and replaced at no cost to the project.

A survey (see Appendix C) was sent to all trial participants to evaluate the trap from a user viewpoint by Dr. E Murphy (DOC). There were many problems identified with the trial, the worst of which was that one set of traps was dumped yet data was still received from this DOC site. Another problem was that a contractor failed to bait the trial traps because he was not paid to tend these extra traps. Yet another problem was that the traps were sprayed with CRC (rust prevention spray), supposedly to help the movement of parts. However, the CRC would likely have acted as a deterrent for animals. Another site had new staff who knew nothing of the trial and the traps were lost. Despite these challenges the trap found favour with landcare groups and the general public for its ease of use.

The Thumper trap was also tested by Manaaki Whenua Landcare Research Ltd staff on 10 stoats (Table 4) to find out if the trap would achieve the highest classification under the NAWAC guidelines. The trap achieved Class A status (Figure 25), the highest rating for a kill trap.

Pen trials were conducted by Nick Poutu, Manaaki Whenua Landcare Research Ltd at the Johnson Research centre covered by their "in house" animal ethics blanket approval for trap research coverage.

Figure 25. Stoat struck on head in Thumper trap pen trial

Table 4. Thumper Stoat Kill Trial Results (Data courtesy of Manaaki Whenua Landcare Research Ltd.)

Weight (kg)	Sex	Palpebral reflex (min:sec)	Heart stop (min:sec)	Strike location
0.299	Male	<0:30	3:07	Top of skull, just forward of ears; rear jaw.
0.139	Male	<0:30	2:39	Skull, across one ear; rear jaw.
0.300	Male	<0:30	2:20	Top of skull, across ears; rear jaw.
0.242	Male	<0:20	3:31	Top of skull, just forward of ears; rear jaw.
0.206	Male	<0:10	3:10	Top of skull, just forward of ears; rear jaw.
0.197	Female	<0:20	3:20	Just behind eyes; behind jaw + foot.
0.306	Male	<0:20	3:30	Skull, between eyes and ears; rear jaw.
0.265	Male	<0:20	3:24	Skull, between ears and eyes; rear jaw.
0.171	Female	<0:15	3:03	Top of skull, across ears; behind jaw.
0.293	Male	<0:20	1:24	Top of skull, between eyes and ears; rear jaw.

4.13 Trial at Queenstown: Barry Lawrence (comparing Thumpers against Fenns)

DOC's Wakatipu Area Office (Otago Conservancy) carried out a trial of Thumper stoat traps compared with double Fenn sets over the 2004 and 2005 seasons and provide the data analysis. This trial was conducted in the Dart Valley, with most traps being in a line down the true left, and a few at the beginning of the Rock Burn and Beans Burn rivers.

There were 100 of each trap type alternated 200 m apart along a line. Traps were baited with unbroken hens' eggs. Generally there was only one check and bait renewal every three months, but an additional check occurred when stoats and rats were numerous. Both trap types were subject to the same check effort.

4.13.1 Results

The mean catch per three month season over both years was 16 stoats/100 traps for Fenns and 4.5 stoats/100 traps for Thumpers. This difference was statistically very significant: $p<0.001$ (2 sample t test), i.e., the Fenns caught almost four times as many stoats as the Thumpers.

The Fenn traps always caught more stoats (Table 5) than the Thumper traps. The 2005 year was considered a stoat explosion year (i.e., a mast event, see for example Fitzgerald et al., (2004) for an explanation of this ecological phenomenon in New Zealand beech forests), with 117 stoats being caught. The reason for separating the data out into seasons is that the younger stoats appear in the Summer/Autumn period and they are of smaller size. It was considered that the smaller animals could potentially have problems pushing the trigger plate (Figure 26).

Table 5. Comparison Between Fenn and Thumper Trap Kill Rate for Stoats in Wakatipu Trial. (data courtesy of DOC's Wakatipu Area Office)

Year and Season	Fenn	Thumper
2004	35	12
2005	93	24
Winter	12	5
Spring	12	5
Winter/Spring	24	10
Summer	52	16
Autumn	52	10
Summer/ Autumn	104	26
Average Sprung traps/season	5.5	4.7

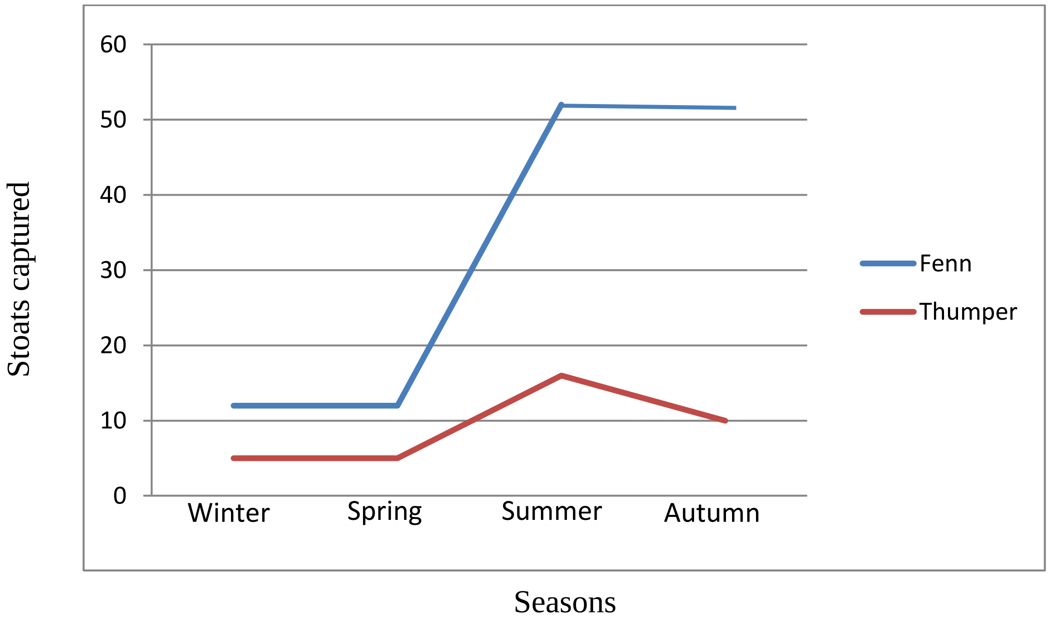


Figure 26. Seasonal mean stoat kill at Wakatipu 2004-2005

The total stoat catch rate varied markedly between years, with the total catch being 47 in 2004 and 117 in 2005. In a 'normal stoat year", in this case 2004, the mean seasonal catch for Thumpers was 3.2, compared with 8.4 for Fenns ($p=0.003$). However, in a partial eruption year (2005) the mean seasonal catch for Thumpers was 5.7 compared with 23.7 for Fenns ($p<0.0001$).

Two rats were caught in the Thumpers and 90 caught in the Fenns during the Wakatipu trial. This was an interesting result and a further study (see section 4.14) was done to compare the catch rate of Thumpers versus the Victor snap trap for rats.

4.14 Investigation of Rat Trapping: Comparing Thumper against Victor

A trial was conducted at Parihaka Scenic Reserve (Parihaka) in Whangarei by Northland Polytechnic student Joe Lloyd-Jones (Lloyd-Jones, 2004). The investigation was to determine the catch rate of rats to see if it replicated that which occurred in the Queenstown trial, and to record the weight of the rats caught. "The Victor caught 18 and Thumper traps caught 2. The difference in numbers of rats caught in the Victors and Thumpers significantly different at $p<0.001$ (Lloyd-Jones, 2004, p. 11).

4.15 Design 1 Conclusions

The Thumper trap proved to be a very easy trap to set and achieved the aim of mimicking the setting style of the Timms trap. However, there were many lessons learnt:

Lesson Learnt: *A high performance of a trap in a NAWAC pen test does not neccesarlty mean a high efficacy in the field.*

Lesson Learnt: *There may be resistance of DOC staff "helping" with the trap trial towards new traps.*

Lesson Learnt: *It is very difficult to conduct trials at multiple locations and trials should be easy for the researcher to access.*

Lesson Learnt: *By using a trigger system to exclude rats it also has the potential to exclude stoats.*

Lesson Learnt: *The triggering mechanism used can greatly affect the trap performance.*

Lesson Learnt*: The kill force to achieve a Class A trap for a head strike has been established.*

Having identified that the triggering system was affecting the efficacy, the design problem switched to looking at the other triggering systems as proposed in section 4.7. Even though the efficacy was not as high as desired a major accomplishment was achieving the Class A trap classification under NAWAC. The DOC funding meant that the trap needed to pass the animal welfare considerations before it could be field tested. The design flow path for the invention of Thumper trap is shown in Figure 27.

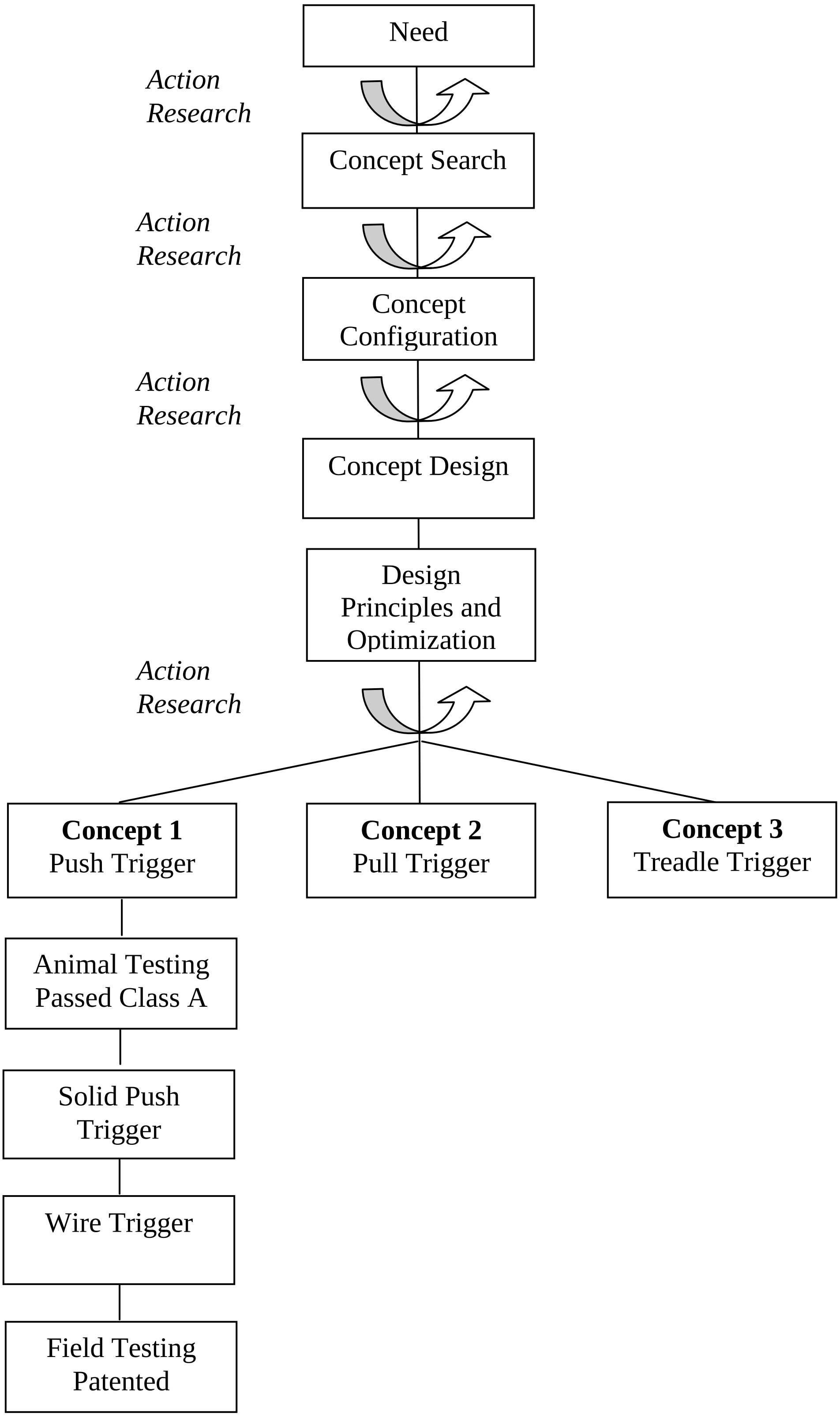


Figure 27. Design flow chart for Thumper

The second prototype concept, as detailed in section 4.7, utilised a treadle trigger replacing the push trigger. In this case the spring will not be over-centre, but positively loaded in the downward direction and restrained by the trigger (see Chapter 5).

Chapter 5

Design 2: Stoats – Development and Evaluation of "Dominus"

The second prototype concept, as discussed in section 4.7, utilised a treadle trigger replacing the push trigger. In this case the spring will not over-centre, but positively loaded in the downward direction and retrained by the trigger.

5.1 Design Principles and Optimisation of Design Layout: Dominus

As part of the Cooperative Inquiry approach a survey of end users conducted by Dr. E. Murphy (Appendix C is a copy of the survey form) gave clues for future design changes. The design change recommendations from survey participants was incorporated in the existing Thumper trap design by using a treadle trigger system. The resulting trap design was called "Dominus" (Figure 28).

The Dominus trap needed to have the option to incorporate the push-type trigger (as used in the Thumper trap) as I wanted to know if the triggering system was affecting the catch rate. As well as the treadle trigger, the Dominus trap had additional design requirements including:

- the ability to be assembled in the field with no tools
- the trap body needing to stack like flower pots to decrease space
- single traps able to be modified to become a double set
- trap able to be baited without removing pegs used as ground mounting system
- trap able to self-set like Thumper, i.e., 'pull on a string' setting system.

There was also anecdotal evidence (M. Bygate, pers. comm., 2003) that stoats are sensitive to heat change when standing on a metal treadle, which may account for low catch rates in winter and for this reason plastic was chosen for the treadle. A low co-efficient of friction was also required between the setting arm (see Appendix A) and the treadle plate. For this reason, the setting arm was also made of plastic.

5.2 Manufacturing Design Principles

The treadle and trigger arm needed to be made of plastic. Since making plastic extrusion dyes for these parts would cost in excess of $15,000 each, the cheaper alternative was to punch the parts from a plastic sheet. A source of 4 mm recycled plastic sheet was located and the idea of using recycled plastic parts to catch environmental pests became an appealing concept (i.e., incorporating recycling is consistent with the conservation principles associated with the goals of these traps). Next, punch dyes needed to be designed to manufacture these parts. An investigation also was carried out to determine if the entire trap body could be manufactured from recycled plastic, as using virgin plastic would be too expensive and less environmentally friendly.

5.3 Engineering Drawings

A 3D model was created in SolidWorks®. The design was again shown to DOC and volunteer groups for feedback with no real changes recommended. The drawings for the Dominus trap are shown in Figure 28 along with the flattened form (Figure 29).

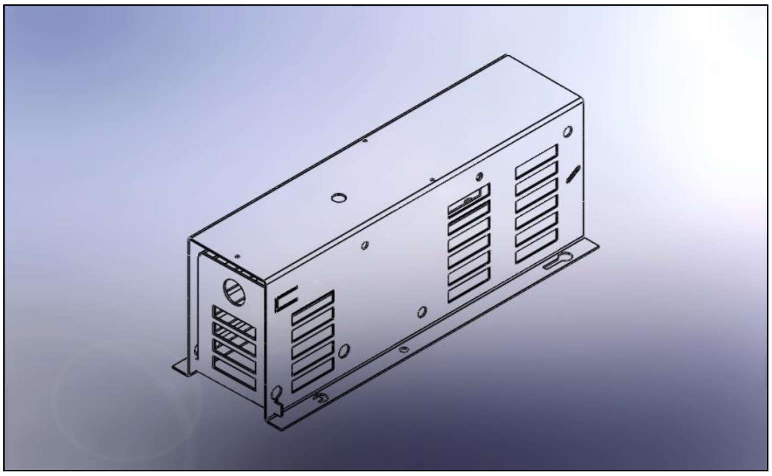


Figure 28. Dominus 3D SolidWorks® model (source: Ian Domigan)

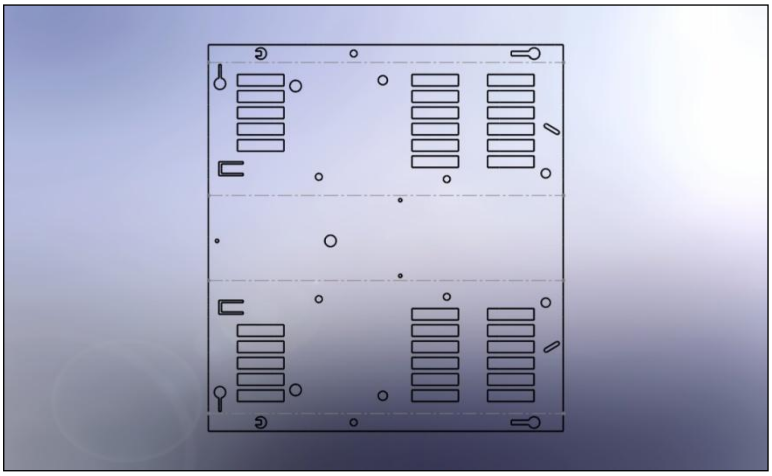


Figure 29. Dominus flattened punch form (source: Ian Domigan)

5.4 Dominus Prototypes

Three forms of the Dominus trap prototypes were made. The first was to allow for both trigger systems (i.e., push or treadle) to be interchanged at will using the same trap body. This was done to investigate the influence the triggering system was having on catch rate. The second was a body that allowed only for a treadle type system (Figure 30). The reason for this was that this triggering system no longer operated on an over-centred spring design, but required that the spring was positively loaded for the triggers to work. The third was a positively-loaded spring with the body also made of recycled plastic (Figure 31). To manufacture this body a plastic hole punch dye was made that punched all the holes in one operation.

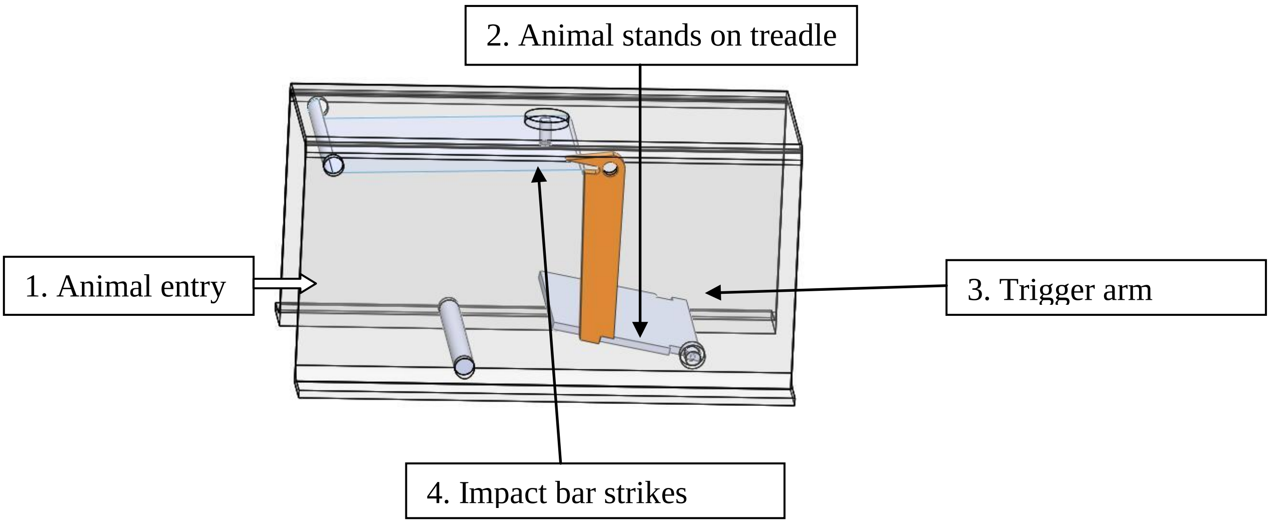


Figure 30. Metal Dominus with plastic treadle plate (source: Ian Domigan)

Figure 31. Dominus trap with a plastic body (source: Ian Domigan)

5.5 Dominus Trap Evaluation

Dominus versus the Fenn Traps:

The Dominus prototype traps were evaluated against Fenn Mk 6 traps (see Appendix A for results) with the Dominus trapping more stoats than the Fenn Mk 6, however, with the low numbers caught no statistical difference was determined.

To determine the variability in trapping rate that could be attributed to the triggering system a separate field trial comparing the push-trigger and treadle-trigger (section 5.6) versions of the Dominus prototypes was undertaken.

5.6 Dominus with Different Trigger Systems

Seventy-two single Dominus traps were set in a double configuration, making a total of 36 individual trap sites. The traps were faced back-to-back and shared common rabbit bait (Figure 32). The major difference between the trigger systems was that to get to the bait the animal had two options: to enter against the push trigger or to enter via the treadle trigger. The traps were set in Stony Bay, near Flea Bay (Banks Peninsula) where the trial between

Dominus versus Fenns was being conducted. The traps were set over a 3 month period in February 2007. Traps were baited with Erase® pureed rabbit, and checked every two weeks. The trial lasted for a total of 78 days (Table 6) and only captured 2 stoats.

Table 6. Comparison of Trigger Configurations Used in the Dominus Trap

Trigger configuration	Stoat	Hedgehog	Rat
Push	0	0	0
Treadle	2	6	1

Figure 32. Dominus traps set in double configuration (source: Ian Domigan)

The Dominus trap set in a double configuration, being two separate traps, ensured that when one side was triggered the other side did not. The traps did not self trigger as the shock of trap triggering was not transferred to the other trap due to the 3-4 mm separation distance. If a consistent knot was tied in the pull string, its position indicated if the trap had been triggered, due to the triggered string length as opposed to the set string length. This knot location allowed for quick checking if the bait was not to be replaced.

Dominus flowchart:

The development flow chart is concept 3 (treadle trigger) of the development flow chart for the Thumper trap (section 4.15) and this arm is represented in Figure 33.

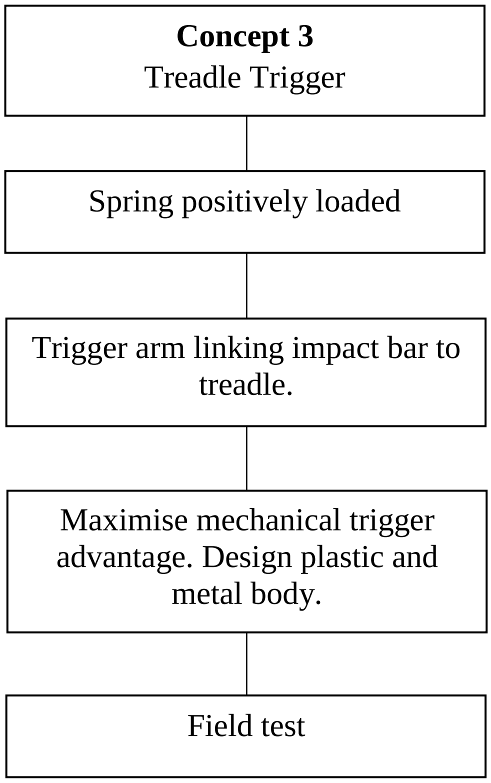


Figure 33. Design flow chart of Dominus

5.7 Design 2 Conclusions

Many lessons were learnt from the progression from the Thumper trap to the Dominus trap and this section should be read in conjunction with Appendix A which describes the development of Dominus in more detail.

Lesson Learnt: *The use of recycled plastic enabled low friction pivots and a cheap trap body.*

Lesson Learnt: *The pull on the string system provided a method to determine if the trap had fired.*

Lesson Learnt: *Having the traps as separate identities in a double configuration prevented one trap from setting the other off as opposed to sharing a common body.*

Chapter 6

Stoat Trap Comparison

In this section the Trap Factor developed in the Methodology Chapter (section 3.5.12) is applied to compare the performance of the two traps developed (Thumper in chapter 4 and Dominus in chapter 5). First, the Thumper and Dominus are compared against the Fenn Mk 6 to catch stoats (section 6.1-6.2). Second, the Thumper trap was compared to the Victor rat trap for catching rats, as rats are either bi-catch or a target species of some stoat traps (section 6.3). The Trap Factor is applied to other researchers' published data, to determine if the Trap Factor result is consistent with researchers' conclusions (section 6.4) regarding trap performance. This chapter concludes by conducting a review of trap weight in relation to the target animal (section 6.5) to justify the low placement factor (section 3.5.12) for the DOC trap series.

The Trap Factor comprises of the following variables: selectivity, humaneness, placement, efficiency, annual cost and ease of use as described in section 3.5.12. The selectivity variable is to ensure that a trap is not catching native species and consequently has a 1 or 0 rating. If a trap was to perform well in all other variables but caught native species, needing to be protected, it would instantly get a 0 and ultimately a Trap Factor value of 0. The "ease of use" variable is a subjective measurement which could be influenced by the target end users, e.g., are the traps to be used by commercial trappers or volunteers? The humaneness variable is based on the humaneness rating as a result of the NAWAC trap testing results as outlined in section 3.5.12. The other variables are based on trap ratio comparisons; therefore, the Trap Factor gives a holistic comparison of two traps as opposed to just concentrating on catch rate. The key question to be answered is: "Does the trap factor equation give realistic results?"

6.1 Comparing Thumper with Fenn (Mk 6) for Catching Stoats

The data for this comparison can be found in section 4.13 with the trial being conducted by Barry Laurence of DOC Queenstown.

Trap Factor = selectivity*humaneness*placement*efficiency*annual cost*ease of use

Selectivity:

Both the Thumper and Fenn Mk 6 with Philproof covers did not catch any native species in this trial. Therefore, both have selectivity = **1.0**

Humaneness:

The Fenn trap has been tested against the NAWAC guidelines (Appendix B):

Fenn **= 0.25** (Failed NAWAC)

Thumper = **1.0** (passed NAWAC)

Placement:

Number carried in a pack: 20 kg max weight

75 l max volume

Thumper = **20** (20 by weight (each trap weight 1 kg) with 31 by volume (each trap's volume is 2.4 l)

Fenn Mk 6 + Philproof cover = **17** (each unit 1.2 kg (covers stack so weight governs))

Thumper trap placement = Thumper/ (Thumper + Fenn Mk 6)

= 20/(20+17) = **0.54**

Fenn trap placement Mk 6 = **0.46**

Efficiency: (see Table 5 section 4.13)

Efficiency Thumper = (number caught by Thumper)/(total number caught)

= 36/(128+36) = **0.22**

Efficiency Fenn Mk 6 = **0.78**

Annual cost:

Fenn Mk 6 trap ($27/trap + $25/cover) lasting for 10 years = $5.20/year

Thumper cost $25/trap lasting for 10 years = $2.50/year

Annual cost factor Thumper = 1-($2.50/($5.20 + $2.50)) = **0.68**

Annual cost factor Fenn Mk 6 = 1-($5.20/($5.20+ $2.50)) = **0.32**

Ease of use:

Both traps had the same complexity of use for the commercial trappers (R. Burly, pers. comm., 2005)

Thumper = Fenn Mk 6 = **1.0**

Applying the Trap Factor

Trap Factor = selectivity*humaneness*placement*efficiency*annual cost*ease of use

From Table 7 it is clear that a humane trap has a distinct advantage over an inhumane trap even if the efficiency was not as great. The inhumane trap needs a clear dominance in one of the remaining criteria if it is to score a higher Trap Factor. An example of this is shown below where the Fenn has a higher evaluation than a humane trap for the catching of rats (section 6.3).

Table 7. Comparative Trap Factor Evaluation of Thumper and Fenn Mk 6 for Catching Stoats

Trap	Selectivity	Humaneness	Placement	Efficiency	Annual cost	Ease of use	**Trap Factor**
Thumper	1.0	1.0	0.54	0.22	0.68	1.0	**0.08**
Fenn Mk 6	1.0	0.25	0.46	0.78	0.32	1.0	**0.03**

6.2 Comparing Dominus with Fenn (Mk 6) for Catching Stoats

The field trial was conducted by DOC Akaroa (see the catch data Table 2, Appendix A). The traps formed part of a defensive perimeter around a little blue penguin breeding colony.

<u>Selectivity:</u>

The Fenn Mk 6 and Dominus did not capture any native species during this trial.

Fenn Mk 6 = Dominus = 1.0

<u>Humaneness:</u>

The Fenn Mk 6 has been tested against the NAWAC guidelines (see Appendix B). The Dominus trap has the same spring power and configuration as the Thumper except the trigger system, (i.e., push (Thumper) and treadle (Dominus)); and the humane rating of Thumper is applied to Dominus.

Fenn Mk 6 = 0.25

Dominus = 1.0

Placement:

In this trial the traps could be placed by the use of a 4 wheeler, therefore, the weight and volume of traps was not as important as in the case when traps needed to be carried. Even though in this trial the traps were placed via a 4 wheeler the case of having to carry (backpack) the traps in is considered in the Trap Factor equation, because it shows the sensitivity of the Trap Factor to placement.

Backpack

Dominus (0.6 kg, 2.7 l) (33 by weight, 27 by volume) = 27 traps

Fenn Mk 6 = 17 (section 6.1)

Dominus Trap placement = Number of Dominus/ (Dominus + Fenn Mk 6)

= 27/(27 +17) = 0.61

Fenn Mk 6 Trap placement = 0.39

4 wheeler

Trap Placement Dominus = Fenn = **1.0**

Efficiency: (see catch data Table 3 Appendix A)

Dominus = (number caught Dominus)/(total number caught)

= 10/(10+8) = 0.55

Fenn Mk 6 = 0.45

Annual Cost:

The Dominus trap cost the same as the Thumper trap so the annual cost factors calculated in section 6.1 apply.

Dominus = 0.68

Fenn Mk 6 = 0.32

Applying the Trap Factor

Trap Factor = Selectivity*Humaneness*placement*efficiency*annual cost*ease of use

The Dominus trap dominates (Table 8) all criteria and the Trap Factor quantifies this by showing a commanding rating over the Fenn trap. If the trap placement was using a 4 wheeler or a backpack the Dominus trap still had a higher Trap Factor.

Table 8. Evaluation of Dominus and Fenn Mk 6 for Catching Stoats

Trap	Selectivity	Humaneness	Placement	Efficiency	Annual cost	Ease of use	**Trap Factor**
Dominus	1.0	1.0	1.0 (4 wheeler)	0.55	0.68	1.0	**0.37**
	1.0	1.0	0.61 (backpack)	0.55	0.68	1.0	**0.23**
Fenn Mk 6	1.0	0.25	1.0 (4 wheeler)	0.45	0.32	0.9	**0.03**
	1.0	.25	0.32 (backpack)	0.45	0.32	0.9	**0.01**

6.3 Comparing Thumper with Victor Rat Trap

This trial was conducted by Lloyd-Jones (2004) to compare the catch rate of Thumpers and the Victor rat traps. Applying the Trap Factor:

Selectivity:

No non target species were caught therefore both traps have a selectivity value of 1.0.

Selectivity Thumper = Victor = **1.0**

Humaneness:

Both traps have passed the humaneness standards.

Humaneness Thumper = Victor rat trap =**1.0**

Placement:

Thumper = **20** (section 6.1)

Victor rat trap + plastic cover (Weight = 0.6kg, Volume 2.4 l)

Number of Victor rat trap + cover based on volume = 75 l/ 2.4 l = 29

Number of Victor rat trap + cover based on weight = 20 kg/ 0.6 kg = 33

Victor rat trap + cover = **29**

Thumper trap placement = Thumper / (Thumper + Victor rat trap + cover)

= 20 / (20 +29) = **0.41**

Victor rat trap placement = **0.59**

Efficiency:

Thumper = 0.1

Victor rat trap = 0.9

Annual cost:

Victor rat trap cost $10 with cover and lasts 5 years = $2/year

Thumper cost $25/trap lasting for 10 years = $2.50/year

Annual cost factor Thumper = 1-($2.50/($2.00 + $2.50)) = **0.44**

Annual cost factor Victor rat trap = 1-($2.00/($2.00+ $2.50)) = **0.56**

Ease of use:

The Thumper was considered easier to use than the Victor rat trap (R. Burly, pers. comm., 2004) and was considered to be easier to clean and set.

Thumper ease of use = **1.0**

Victor rat trap = **0.9**

Applying the Trap Factor

Trap Factor = selectivity*humaneness*placement*efficiency*annual cost*ease of use

This comparison and evaluation (Table 9) demonstrates the ability of the Trap Factor to compare two or more traps that have met a humane standard. This then means that the trap factor comprises of the remaining five criteria, with the Victor rat trap being dominant in efficiency and lower annual cost justifies its high Trap Factor rating.

Table 9. Evaluation of Thumper and Victor Rat Trap for Catching Rats

Trap	Selectivity	Humaneness	Placement	Efficiency	Annual cost	Ease of use	**Trap Factor**
Thumper	1.0	1.0	0.41	0.1	0.44	1.0	**0.02**
Victor	1.0	1.0	0.59	0.9	0.56	0.9	**0.27**

6.4 Applying Trap Factor Methodology to Existing Data

The Trap Factor methodology is now applied to other researchers' data and questions: "Does the trap factor support the researcher's conclusion?" A study between DOC 200 and Victor rat traps by Kirk & Gillies (2008) was selected because it involves the comparison of a newly developed "humane" trap (DOC 200) against an iconic rat trap (Victor rat trap). The catch totals were:

Victor: 174 rats

DOC 200: 218 rats.

Kirk & Gillies (2008) determined that the DOC 200 was the better trap. However, when the Trap Factor Method is applied to Kirk & Gillies (2008) data different results and conclusions are obtained (Table 10). The results of taking into account more than just the catch rate show a completely different answer to that obtained by Kirk & Gillies (2008).

<u>Selectivity:</u>

Both traps, when appropriate covers and baits are used, did not catch protected species (Kirk & Gillies, 2008).

Selectivity Victor = 1.0

Selectivity DOC 200 = 1.0

<u>Humaneness:</u>

Both traps have passed the humaneness standards.

Humaneness DOC 200 Thumper = Victor rat trap = **1.0**

<u>Efficiency:</u> (see catch totals above)

Victor = 174/ (174 + 218) = **0.44**

DOC 200 = 218/ (174 +218) = **0.56**

<u>Trap placement factor:</u>

Trap placement was based on the ability of a person to carry the traps, i.e., a person can carry 29 Victor rat traps and covers as opposed to a maximum of two DOC 200 trap sets. Each trap set weighs 9 kg.

Trap placement factor Victor 29/ (29 + 2) = **0.94**

Trap placement factor DOC 200 = 2/(29 + 2) = **0.06**

<u>Annual cost:</u>

Victor rat trap costs $10 with cover and lasts 5 years = $2/year

DOC 200 + Box costs $70 and lasts 10 years = $7/year

Victor (1-2/9) = **0.77**

DOC 200 (1-7/9) = **0.22**

<u>Ease of Use:</u>

From my own experience using both these traps (Howards Hole field trial using DOC 200, and Victor rat traps as a volunteer trapping rats in Little River in 2004), the DOC 200 and Victor rat trap were easy to set but the DOC 200 more difficult to clean.

Victor rat trap ease of use = 1.0

DOC 200 ease of use = 0.9

Trap Factor = selectivity * humaneness * placement * efficiency * annual cost * ease of use

Table 10. Comparative Trap Factor Evaluation of Victor and DOC 200 for Catching Rats

Trap	Selectivity	Humaneness	Placement	Efficiency	Annual cost	Ease of use	**Trap Factor**
Victor	1.0	1.0	0.94	0.44	0.77	1.0	**0.318**
DOC 200	1.0	1.0	0.06	0.56	0.22	0.9	**0.007**

The conclusion drawn by Kirk & Gillies (2008) (DOC Northland), was that the DOC 200 trap was significantly better at catching rats than the Victor rat trap, which was true when only catch rate was considered. When their results were put into the Trap Factor equation (Table 10) the opposite result was drawn. The sensitivity of this finding can be tested further. If the traps were located in open country, e.g., dry river beds or open farm land the placement factor would be 1.0 for both the Victor rat trap and DOC 200 traps. The subsequent Trap Factor would be:

Victor rat trap = 0.339

DOC 200 = 0.101

This demonstrates that even in open country the Victor rat trap has a higher Trap Factor than the DOC 200. Also demonstrated is the interrelationship between the efficiency and annual cost factors, for the case when all other Trap Factor values are unity, or close to it. The Victor rat trap being a much cheaper trap may not need to be as efficient compared to a more expensive trap, e.g., DOC 200.

6.5 Trap Size Compared to Animal Weight

The comparison between the DOC 200 and Victor rat trap (Table 10) demonstrated that the Trap Factor is very sensitive to a quantum difference between one of the equation variables. In this example the placement factor had a huge effect on the result. This raises the question; "Why is the DOC 200 trap large in comparison to other traps and, what weight trap should be used for a target animal?" To determine the relationship between target animal and trap weight a review of existing traps in New Zealand was conducted (Table 11). The data for the trap weight is from Ragg et al. (2007) with the animal weight for possums (3 kg), ferret (0.45 kg) stoat (0.30 kg) and rat (0.24 kg) being important for comparative reasons only.

Table 11 Relationship Between Animal Weight and Trap Weight

Possum (3.0 kg)		
Trap	**Trap weight (kg)**	**Trap weight/animal weight**
Blitz	1.80	0.6
Carac	1.50	0.5
Set and Forget	0.60	0.2
Holden multikill	0.56	0.2
Timms	1.25	0.4
Warrior	0.95	0.3
Conibear	1.05	0.4
Possum master	0.50	0.2
Sentinel	0.45	0.2
Ferret (0.45 kg)		
Hammer	1.0	2.2
DOC 250	9.50	21.2
Blitz	1.80	4.0
Warrior	0.95	2.1
Possum master	0.50	1.1
Conibear 110	0.80	1.8
Tunnel trap	1.30	2.9
KBL Tunnel	1.35	3.0
Fenn Mk 6	1.40	3.1
Stoats (0.30 kg)		
Fenn Mk 6	1.40	4.7
DOC 200	8.80	29.3
Dominus	0.60	2.0
Hammer	1.00	3.3
Victor	0.60	2.0
Rats (0.24 kg)		
Victor	0.60	2.5
Hammer	1.00	4.2
Dominus	0.60	2.5
DOC 200	8.80	36.7
Fenn Mk 6	1.30	5.4

For trap designers an understanding of trap weight/animal weight provides a guide as to what the target trap weight should be for a particular animal. The DOC 200/DOC 250 are very heavy traps and consequently deserve the significantly low placement factor.

6.6 Conclusion on the Effectiveness of the Trap Factor Equation

The Trap Factor equation gave logical results and was able to effectively compare a trap that had failed the NAWAC Class A or B requirements and yet have a higher catch rate as was the case with the comparison of the Fenn and the Thumper traps. It also gave logical results when comparing the Dominus with the Fenn being able to quantify and compare the high catch rate with humaneness of kill. It also provides a holistic approach to the evaluation of traps that may reverse the conclusions that researchers concluded using just catch rate data.

Lesson learnt: *The Trap Factor equation in a holistic way quantifies the comparative performance of traps.*

Chapter 7

Design 3: Possums – Development and Evaluation of "Bulldog"

The most widely-used traps for killing possums are Timms, Conibear 110 and to a lesser extent the LDL 101 (B. Warburton, pers. comm., 2003). The research into developing a humane possum trap was funded by Manaaki Whenua Landcare Research Ltd. Bruce Warburton, a biologist, gave input considering the animal's ecological and biological perspective, while my input concentrated on engineering aspects. The LDL 101 and BMI 160 (essentially an LDL 101 with stronger springs) have the potential to be humane and capture-efficient (Warburton & Orchard, 1996). The LDL 101 is a Canadian trap that is not commonly used in New Zealand. It requires a cubby to be built to set the trap in (Montague, 2000). Recently a modification of the LDL 101 trap was developed by the pest control company Target Pest Enterprises and called the "Set and Forget" trap.

Research for this thesis indicates the only possum traps to have achieved NAWAC's Class A or B standards are the LDL 101, BMI 160 and the Set and Forget. The Timms trap failed to pass, and compared to the leg-hold traps it is less capture-efficient (Miller, 1993). It is proposed that in the future, leg-hold traps and cage traps will be evaluated on the frequency and severity of various injuries (Montague, 2000).

The following development of a possum trap adheres to the methodology outlined in chapter 3. Because this is a new design and not based on improving previous work, the process starts with the need statement.

7.1 Need Analysis

There is a need for a compact possum kill trap that can achieve Class A or B classification under the NAWAC guidelines. Currently only the LDL 101 and Set and Forget Trap (modified LDL 101 trap) have passed, and are classified as Class B traps. The main problem with these two traps is that they require a separate cubby to be constructed, which substantially increases their weight and decreases their usability.

Need Statement: *To design a compact self–contained possum kill trap that achieves a Class A or B classification under NAWAC guidelines.*

7.2 Concept Search Techniques

The need to cost-effectively kill possums in very large numbers is exclusively a New Zealand problem. There is little basic research to aid trap designers, and for this reason I had to conduct many basic experiments to gain enough ecological and biological understanding to enter the design phase. To understand how the traps physically work, I analysed the engineering performance of current traps.

Previous work by Warburton & Hall (1995) had developed impact momentum curves for possums. This gave me a clear guideline on the amount of energy required to kill a possum. In addition, I studied the Timms trap's impact energy and clamping force. I also looked at the strength and closure time of new and old leg-hold traps described in Warburton & Poutu (2003) as part of trying to understand how traps operate. This work included looking into what made the Conibear such a good trap. The Conibear trap (Figure 34) was identified as having a clear advantage because the springs are large open coils, which act as both a power source and a trap lock (a), which is how most leg-hold traps work. The arms on the Conibear are locked closed by the spring loops moving up the impact arms (Figure 35).

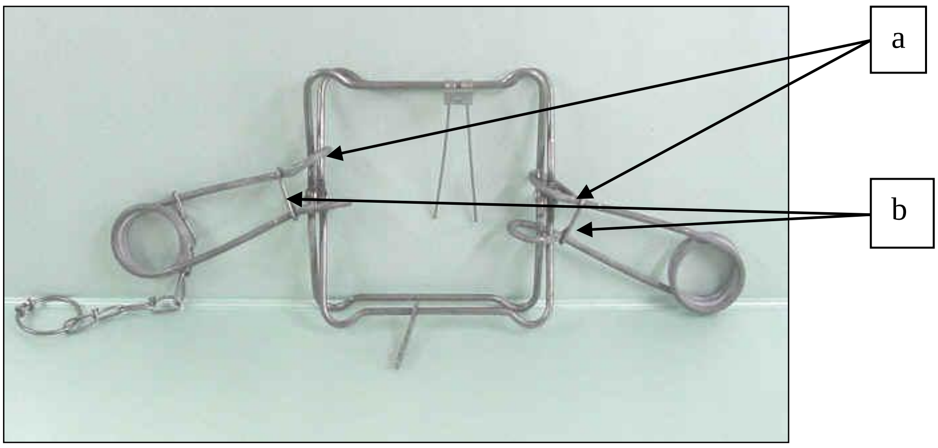


Figure 34. Conibear 120 trap set with safety clips (b) (source: Ian Domigan)

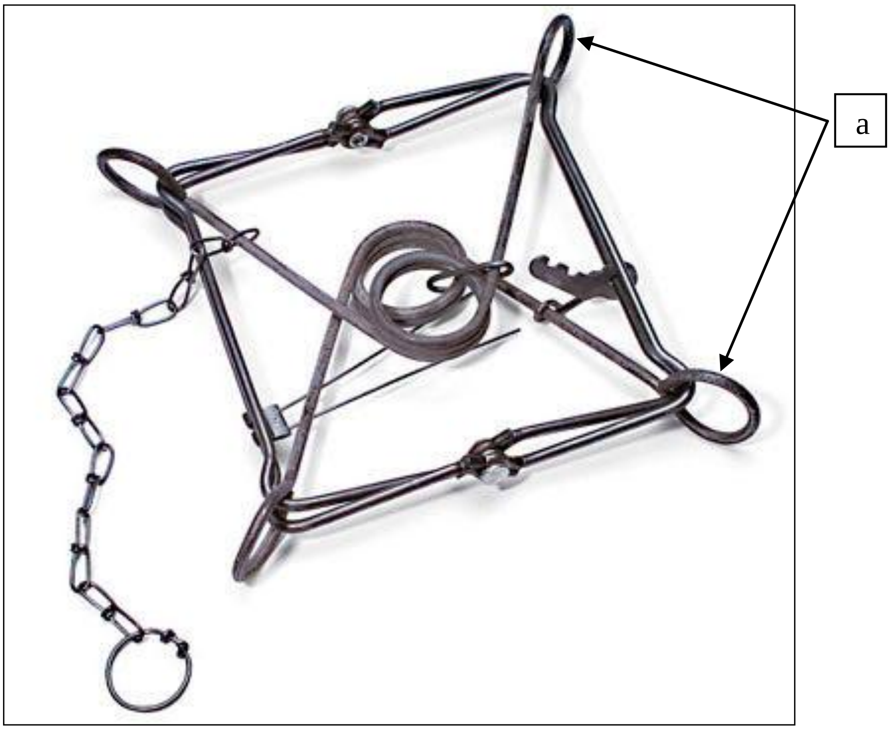


Figure 35. Locking spring loops of the Conibear trap (source: modified from Wikapedia, December 2008)

After the first 10 seconds of being caught, either by a kill trap or a leg-hold trap, possums can make an enormous effort to escape (it initially takes time for them to realise something has happened to them). This struggle lasts about 30 seconds. The force the animal exerts at this time is extreme, and many leg-hold traps have springs attached in their chains to prevent the animal from pulling free. This was also observed by Warburton et al. (2000) during the testing of the Timms trap.

When testing the Conibear traps, using a tensile tester, I noticed that the trap would read a higher number on opening than on closing. This was caused by internal friction in the operation of the trap. This is important because an animal needs to exert more force than the clamping force to open the trap (i.e., it also has to overcome the additional frictional force to escape). For the Conibear 110, this force varied from 6–20 kg depending on the condition of the trap. This finding also led to the conclusion that there are essentially two clamping forces, i.e., trap motion downward and trap motion starting upward, and that friction could be a very useful tool to prevent animal escape.

A pull test rig (Figure 36) was developed, which featured a spring balance with a docking ring (a) that would record the highest force. The test rig was designed to show how hard a possum would pull on a bait. Of the 20 caged possums sampled, all managed to pull to the 1 kg mark (the possums' weights ranged from 2.5 to 5 kg). Observing possums in the catching pens using an infra-red camera during the NAWAC guideline testing, I observed that once a possum latched onto bait they were very resistant to letting it go. Also, I noted that possums entered a trap more than once before actually latching onto the bait.

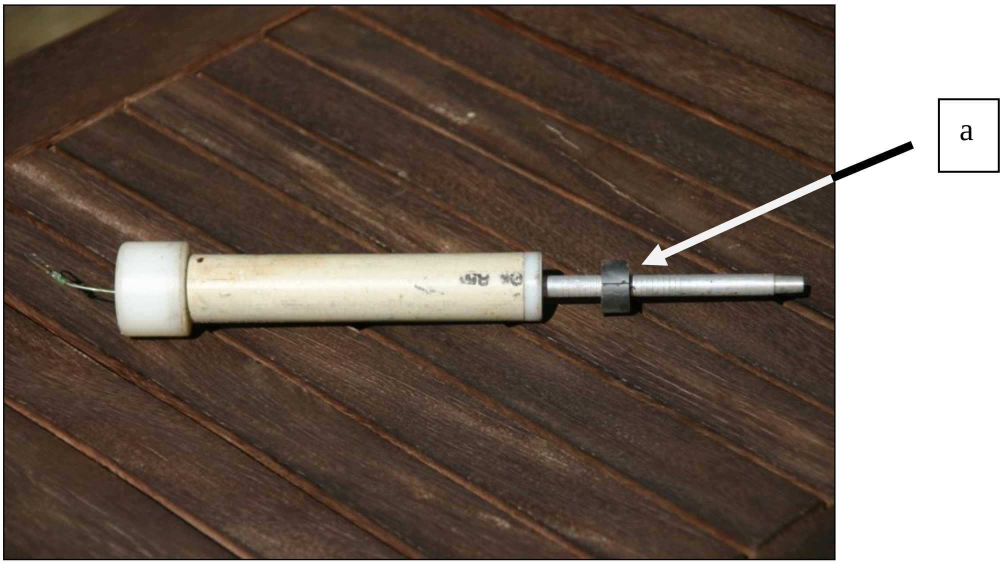


Figure 36. Pull test rig for possums (source: Ian Domigan)

To determine how much a possum would push to get to a bait I made a set of metal circle plates that had peanut butter set at 25 mm behind them. This approach failed as the possum's tongue was longer than 25 mm and they simply licked the bait off. When the bait was moved further away, possums used their paws in preference to pushing on the first spring-loaded plate. This led to the question of when will a possum start to use its paws for a given entry condition. A quick experiment using 20 individually caged possums showed that for a 100 mm diameter pipe, the first possums started using their paws to retrieve the bait when it was placed at 150 mm from the entry (Figure 37). The bait (peanut butter) was placed on a piece of waxed steel (a) set parallel to the entry. It was evident that the possums had been using their paws by scratch marks left in the waxed steel surface.

No possums used their paws to retrieve the bait between 100–125 mm. Two possums retrieved the bait with their paws from 125–150 mm. This result seemed logical as often a possum will be caught by the paw in a Timms trap (D. Hunter, pers. comm., 2004). A Timms trap has an entry hole of approximately 80 mm diameter and a bait position of 150 mm from the entry.

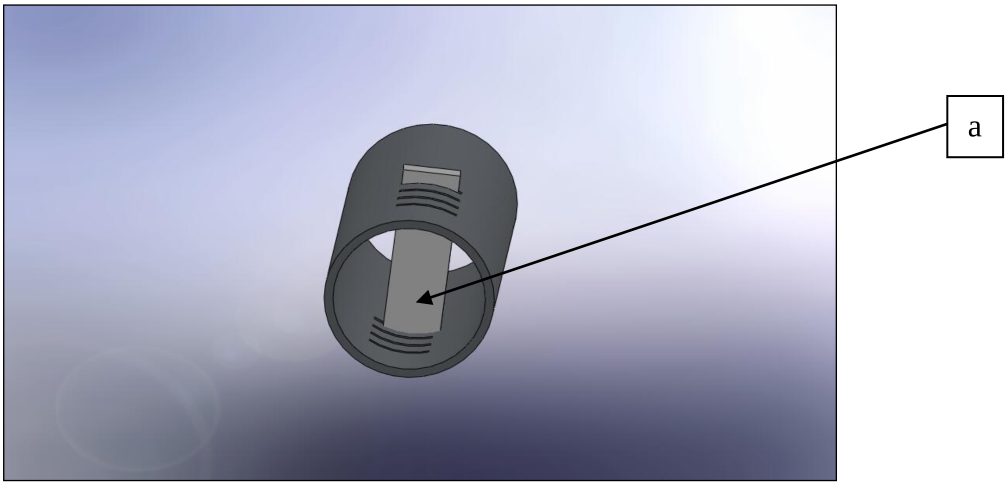


Figure 37. Push plates, with peanut butter on rear plate (source: Ian Domigan)

The strike location for a possum kill trap should be set so as to block off the carotid artery or the windpipe. To achieve this, the trap closure should be around the animal's neck. Possums' heads are consistent in size ((a) in Figure 38). After possums reach 2 kg in weight, there is little variation in head size as they grow (J. Turner, pers. comm., 2004; Crawley, 1973). A possum's head from nose to behind the ears is approximately 100 mm (I. Domigan, unpub. data, 2004). The back of the head curves after the ears, which makes the back of the head an ideal strike location because the possum must expand the trap to extract its head; as opposed to being struck in front of the ears where no great trap expansion would be required. When taking into account the bait size, tongue length (Figure 38 (b)), and the need for the animal to pull before the trap triggers, this means that the trigger needs to be about 125 mm from the entry. The results of this distance-to-bait test indicate that the possum would still be using its mouth as opposed to its paw with the trigger set at this distance.

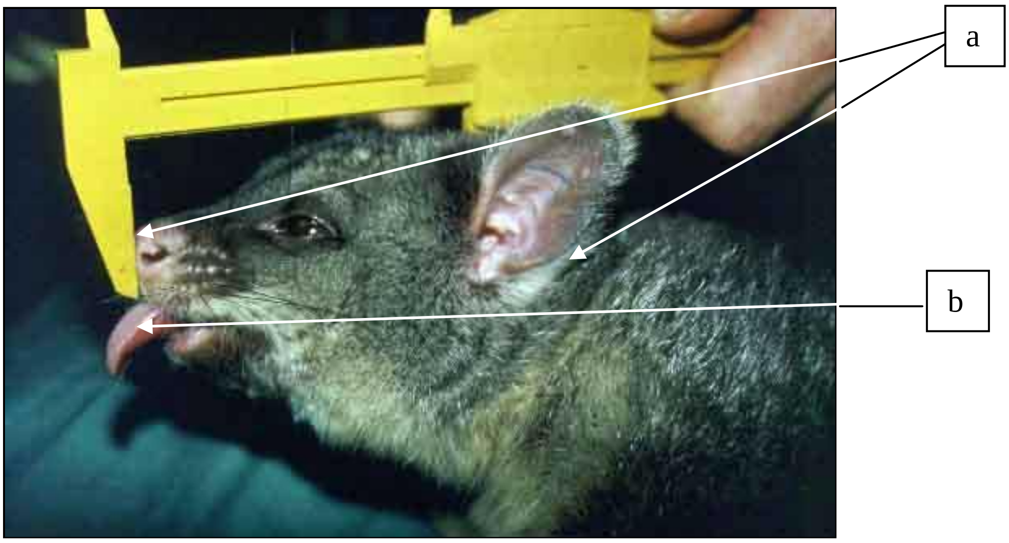


Figure 38. Possum head (modified from Wikapedia, January 2008)

7.3 Concept Configuration

The initial concept of the Bulldog trap was to power two bars together using a piece of spring steel as the power source (Figure 39). The power from the trap comes from the spring steel being bent in a “C” form, and its resistance to opening. This approach is a complete departure from conventional traps, which are powered by tension, compression, or torsion springs.

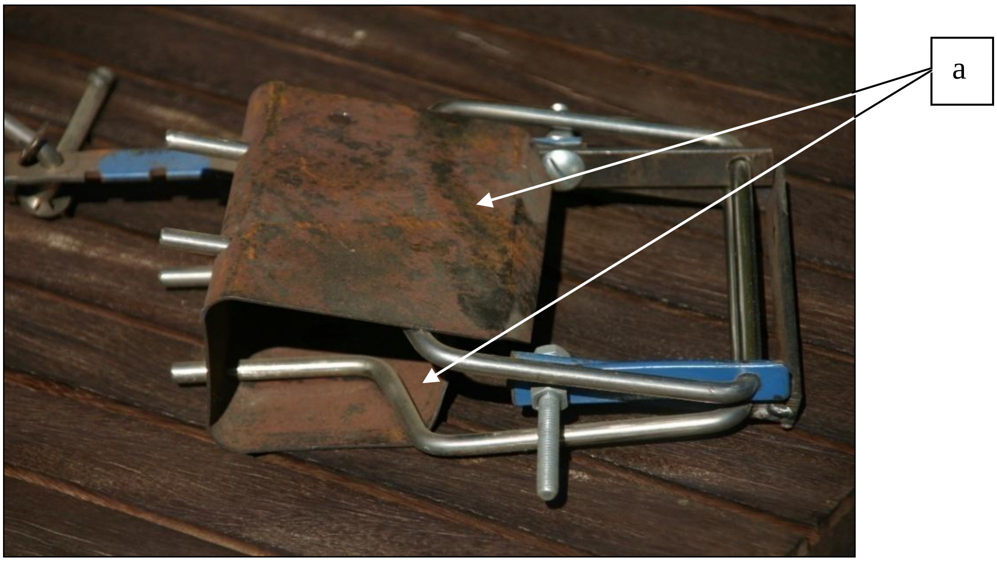


Figure 39. Spring steel “C” powering two metal bars together (source: Ian Domigan)

The impetus for designing this “C” configuration (a) came from my research with Warburton (as acknowledged in Warburton & Poutu, 2003) into how traps work, which showed problems with the springs over time. The main design problems with current springs are:

- they are usually over-tensioned
- the trap relies on the arm strength for a torsion spring
- the loss of tension while under tension when the trap is set (i.e., hysteresis)
- the load increasing as the trap is opened, putting larger demands on triggers and the trap spring retaining system
- traps needing an additional cover to restrict entry.

The use of a sheet spring steel as the power source resolved all the problems compared with the use of conventional springs. The sheet spring steel:

- buckles at a certain load giving a flat spring rate (i.e., it reduces the load on the top end opening force on the spring steel)
- forms part of the trap body and therefore is not trying to pull itself apart (forces are absorbed internally in the spring)

- will actually form part of the trap cover.

7.4 Concept Design for a Humane Spring Steel Trap

Choking or clamping the carotid artery will result in kills in excess of 30 seconds, as animals can hold their breath for longer than this time. This style of trap will only ever be classified as a Class B trap under the NAWAC guidelines.

Other styles of traps either have a locking bar (e.g., Conibear traps) or make it difficult for the animal to actually get to the impact bar by the use of a trap cover. Without these features, the possum could escape by the use of its rear feet.
The three concepts that were developed to try and kill possums humanely were:

1. to place a constricting rubber ring around the possum’s neck, an action triggered via some mechanism.
2. to use a Ramset® charge.
3. to use a piece of flat spring steel bent in a “C” shape that would clamp the throat of the possum.

7.5 Design Principles and Optimisation

These design concepts were varied and it was difficult to decide which one to pursue. I therefore decided to manufacture a test rig to test the principal features of the first three prototype traps.

Prototype 1
A rubber ring (much like a docking ring (used in sheep farming to tail lambs) with an original diameter of 20 mm and a thickness of 5 mm was stretched over an 80 mm pipe. A possum was pushed down the pipe and the ring was released about its neck. The possum lasted longer than the 3 minutes but would have died in time.

Prototype 2
The prototype trap was powered by a Ramset® 7 mm blank to propel a 14 mm rod into the possum’s head. The trap was triggered by the possum pulling on bait, which released the firing pin. The charge then ignited and powered the 14 mm rod straight through the possum’s head. The possum fell from the trap landing upside down with no major muscle reflex

twitching. Death appeared to be instantaneous; however the biggest issue for this trap was operator safety as the 14 mm bolt was not restrained within the confines of the trap.

Prototype 3

The initial design concept (called the Bulldog) was based on the existing Timms and Conibear traps, which have a static clamp load of approximately 5–7 kg at 100 mm opening. The spring was designed to have a clamp load of 10 kg.

For possums, the impact clamp curves have been developed (Warburton & Hall, 1995), which gave an insight into the load requirement needed for blocking the carotid artery. However, what is not considered in the impact clamp curves is the size of the impact bar. Perhaps a better measure would be the stress (load/unit area of the impact bar). The thinner the impact bar, the better the penetration, and ultimately the higher the chance of a quick kill.

Initially the Bulldog trap was constructed using two 6 mm bars (Figure 40). It failed in pen trials, as the possum was able to get its back feet onto the trap impact bar and open the trap far enough to be able to withdraw its head and release itself. There appeared to be a major energy drive from the possum caught in the trap after 20–30 seconds. Having got over the initial fright of what had happened, the possum would then try to escape. If the trap was able to withstand this, I considered that, because the trap had higher clamp characteristics than the Timms trap, the trap would obtain a Class B classification under the NAWAC guidelines.

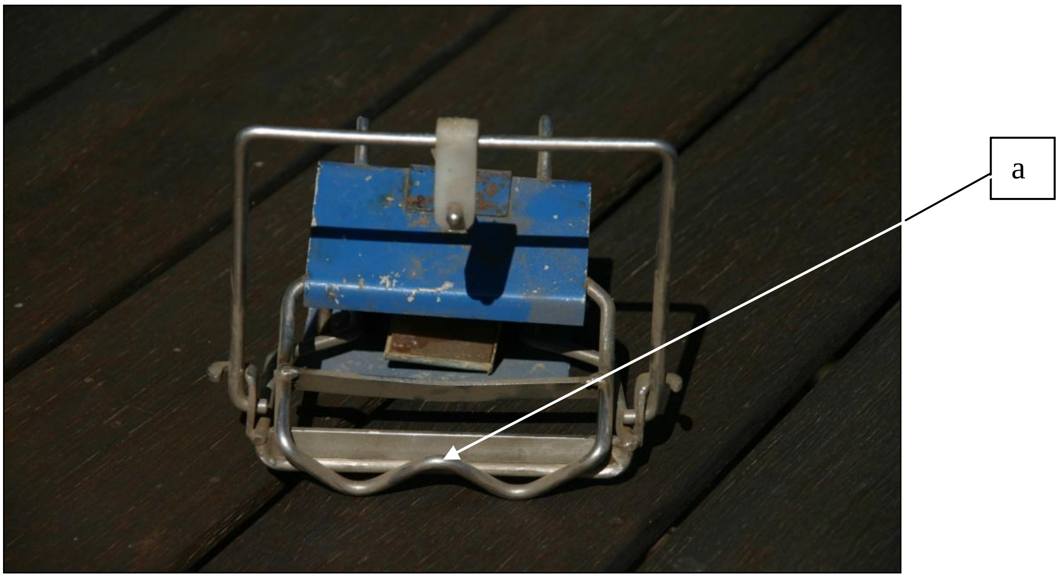


Figure 40. Trial possum trap (source Ian Domigan)

Other styles of traps for possums make it difficult for the animal to get to the impact bar, by the use of a trap cover. Without it, possums could escape by the use of their rear feet, as the clamping force of the trap may be low, e.g., as in the Timms trap.
To prevent the possum from extracting itself, the impact bars were then designed to be wavy ((a) in Figure 40), to make it harder for the possum to slide sideways and potentially escape. This concept was also to provide an orientation point for trap closure, so as to ensure the possum's head was orientated to the middle of the trap, as opposed to getting caught in the sides.

The other important point was that if the trap was fastened to a tree for example, this would provide a means of resistance for the possum to pull against. However, this would also mean that it was difficult for the possum to use its rear feet to escape. The initial concept was to have the trap detach itself from the tree and act as a collar wherever the animal went. The possum always ended up at the bottom of the tree, trying to remove the trap from around its neck. It could only move up to 1–2 m, by thrusting its rear feet.

The trap set in a tree managed to kill three animals in less than 3 minutes and then failed, due to the fourth possum lasting more than 5 minutes. The reason for this failure was that the impact bar was too large (6 mm diameter), and there was insufficient clamp and impact load. A double "C" spring was then pen tested, which increased the clamp load to 15 kg. However, this also failed, due to the possum being able to use its back legs to remove the trap in the 20 second adrenalin rush after initial capture.

7.6 Developing the Body of the Trap

By looking again (as a result of the above 'failures') at the object function diagram (section 3.5.2), it became evident that the trap arms could be made redundant. A redesign was conducted, which made the spring and clamp bar as one. This was achieved by simply folding the spring to the desired shape and inserting pivots, thereby making the spring as the entire trap body with no cubby then being necessary.

Obtaining small quantities of various thin sheet sections to experiment on was difficult, with the 1.9 mm and 2.0 mm sheet having to be imported from Australia and the spring companies failing to supply tempering data for their product. There was a vast difference in the composition of the steels, which resulted in a variation for tempering between thicknesses. The sheet thicknesses worked with were 1.0 mm, 1.1 mm, 1.5 mm, 1.6 mm, 1.9 mm, and 2.0 mm.

If the sheets were not tempered correctly, they would shatter (too brittle) or deform (too plastic). The final tempering that worked for the 1.6 mm sheet was to heat the sheet to 800°C, put in quenching oil to cool, then reheating to 400°C and allow to air cool. All holes had to be drilled prior to tempering, as the spring material was too hard to drill by conventional techniques. Along with the sheet investigation I investigated the tightness of the bend that would supply the desired static clamp, yet not permanently deform when opened. A 50 mm bend was found to provide a satisfactory result (Figure 41).

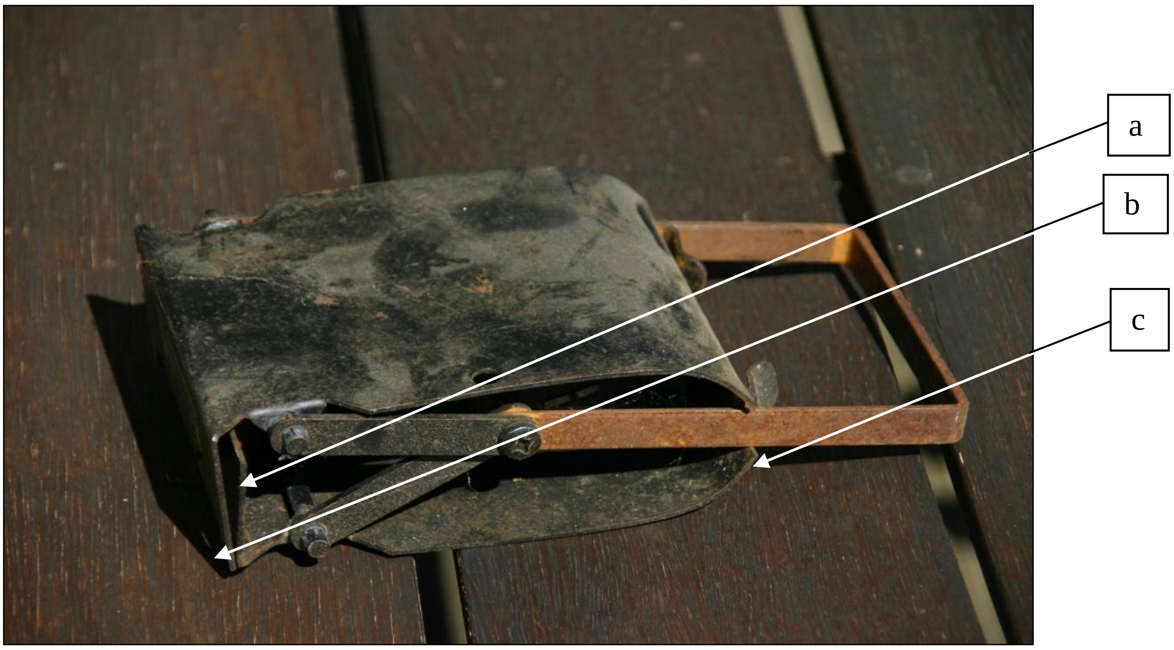


Figure 41. Trap spring steel body (source: Ian Domigan)

The static clamp load of the 1.6 mm spring steel sheet was 20 kg (at 10 mm opening) with the impact edges overlapping by 20 mm (i.e., distance between a-b). This gave a high clamp load by the trap needing to open 30 mm, when essentially only being open 10 mm (Figure 41). This was required as there was no pre-tension possible in the spring steel and if there had been pretension the 50 mm curve (c) yielded when the ends of the trap were opened to 100 mm.

The first prototype bulldog trap failed to render the first possum unconscious within 3 minutes. It appeared that the top clamping jaw went inside the bottom jaw. This configuration allowed the animal to survive longer than 5 minutes. This was strange, considering a trap of lesser clamp had been more successful. Warburton et al. (2000) found when looking at the Timms trap that the opposing jaws led to a slower time to loss of palpebral reflex with little difference between the off-set nature of the jaws.

However, the reason for the failure was that the animal's windpipe was not exposed when the trap bent the animal's head down and this allowed air to still flow. When the clamp jaw was reversed, i.e., (Figure 42) the top jaw (a) closed on the outside of the bottom (b), death occurred within 40–60 seconds. The head was now snapped back as opposed to being pushed forward, making it easier to penetrate to the wind pipe and carotid artery. The loading as the spring opened was complex, as the spring would start to flex in the flat position on opening, giving a variable spring rate.

Figure 42. Overlapping clamp jaws (a & b) (source: Ian Domigan)

To make the trap more weather resistant the springs were iodised, galvanised or powder coated in an effort to prevent rusting. However, these measures failed, as the iodising and galvanising made the springs suffer from hydrogen embrittlement (they snapped), even after placing them in hot water for six hours (pickling). The powder coating upset the spring temper, even though it only reached a baking temperature of 200°C. This result is difficult to explain, as this temperature is far below the tempering temperature of 400°C. A chemical rust-kill protection system was then tried and worked.

7.7 The Trigger

One of the problems with triggers is that generally a very large force needs to be released by a very small force. Mouse traps achieve this via lever arms which reduce the activation force. Others rely on hair triggers, arms holding something apart (over-centre), or latches which are released to activate the trap. The ideal trigger is one which self-sets when a trap is opened, as does the Timms trap, or some mouse traps. This allows for a consistent trigger to be set, as opposed to a trap either being set too fine or coarse by individual trappers.

The first trigger trialled was a push trigger. A push trigger was perceived to be ideal as precise location of the animal would be known for the jaws. With the earlier trials of a push trigger a piece of plastic impregnated with cinnamon, a known possum attractant (Morgan, 1990), was used. The result (I. Domigan, unpub. data) of this trial was that the possum tried to pull the trigger, rather than push on it, or it would lick the trigger and would make the trigger into a hair trigger, which could then fire by knocking the trap. On one occasion a single possum was struck on the head by the top jaw and the animal was found dead in the morning.

A pull trigger (Figure 43) was investigated and instantly there was little problem in catching the possums. A test rig was set up to show how possums responded to different bait sizes. This was not meant to be an in-depth study, but simply an indication for the bait size to be used. If the bait was held rigidly the possum would simply lick it. If the bait was held so it would be free to move, the possum would pull it (I. Domigan, pers. obs., 2004). When the bait size was around 40 mm it was always licked. When the bait size was reduced to 20 mm both licking and pulling occur and at 12 mm it was always pulling. This made sense as it would be like the possum reaching for a berry fruit in nature. The sample size for this trial was 25 animals. These animals were observed in observation pens at dusk over a one week period. The animals were changed every day and new sets introduced.

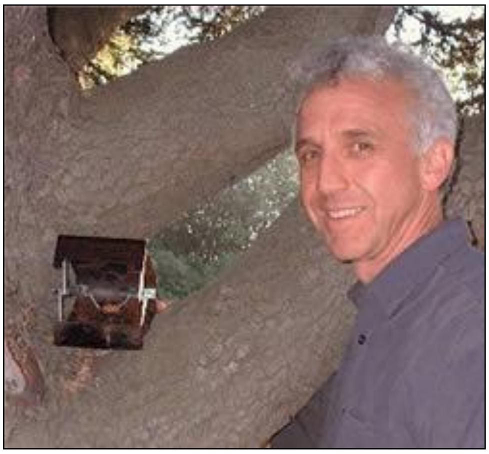


Figure 43. Trap set and Bruce Warburton (source: Manaaki Whenua Landcare Research Ltd)

7.8 Lever Arms

The trap was based on over-centring two lever arms loaded vertically through central pivots. After many designs, the arms were positioned just over the centre, to use the back of the trap as the stop point. The force required to over-centre the arms is minimal, and this provided the mechanical advantage required to release a 20 kg vertical load with a low pull force. The side bars are also important as a means of restricting the side entry to the trap. The trigger arms gave a further reduction in force and a setting load of 0.3 kg was chosen for the commercial model.

7.9 Animal Welfare Classification Testing

Once the final design was completed a sample size of 10 possums was chosen for humaneness testing by Manaaki Whenua Landcare Research Ltd. The trap achieved a B classification under NAWAC guidelines with all animals surviving longer than 30 seconds with a maximum of 80 seconds. The trap with a possum captured is shown in Figure 44.

Figure 44. Possum caught in Bulldog possum trap (source: Connovation Ltd**)**

7.10 Manufacturing Principles

The Bulldog trap was licensed directly to Connovation Ltd, who were to oversee its manufacturing and marketing. There were major delays in the product reaching the market due to Connovation Ltd not understanding that they were given a finished product.

For example, Connovation Ltd put a powder coating on the product, thus changing the trigger system. The product failed, for reasons I have set out earlier (see section 7.6 on effects of powder coating on spring strength). To my knowledge Connovation tried five trigger systems and finally reverted to the one they were supplied with.

This was a very disappointing aspect to the design process. It was evident that the final manufacturing process needs to involve the designer, as others were changing the product without understanding the implications of what they were doing. The complete inventive methodology for the Bulldog is represented in Figure 45.

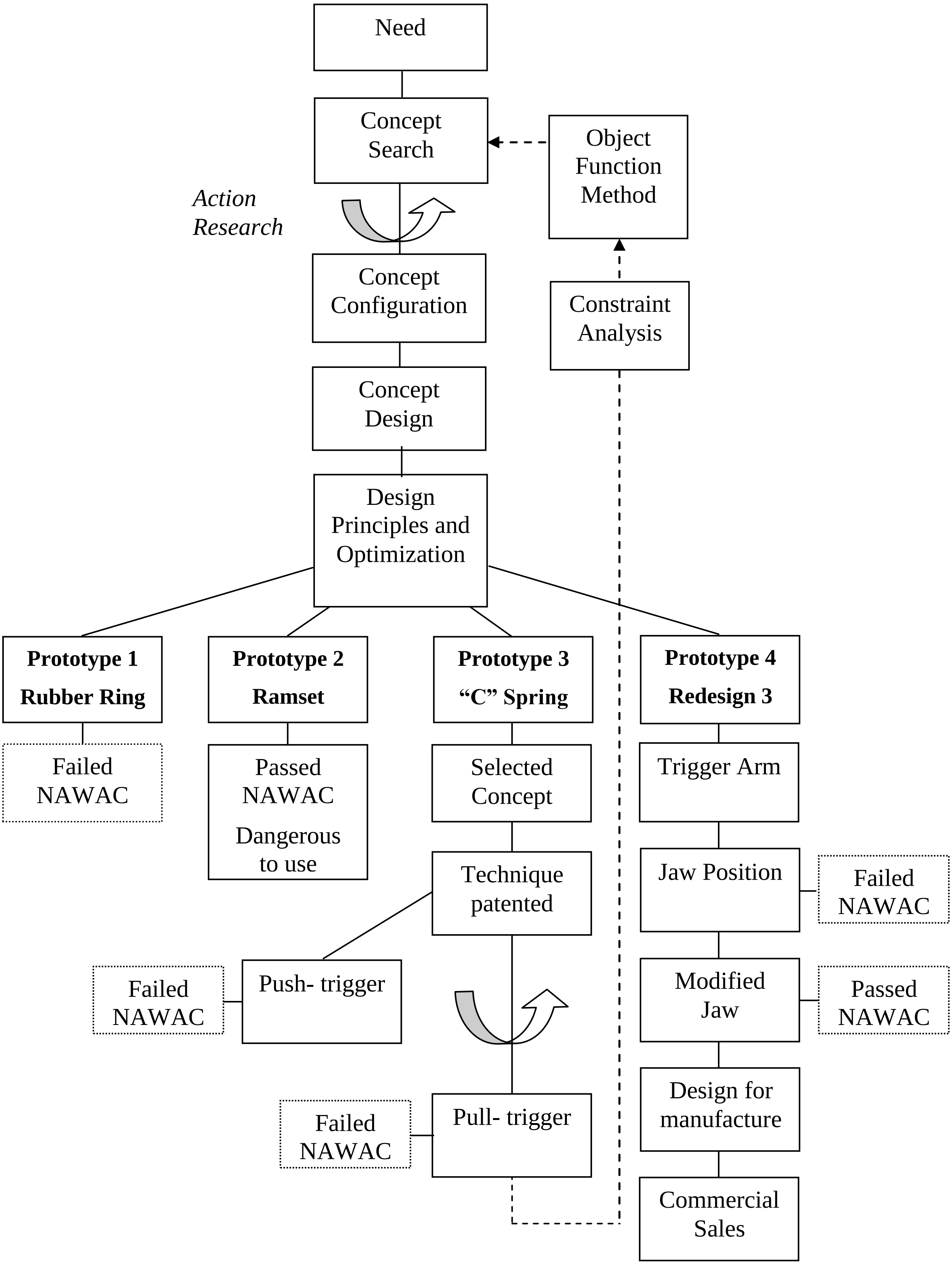


Figure 45. Design flow chart for "Bulldog"

7.11 Design 3 Conclusions

The ultimate design of this trap was a complete success with the innovative methodology also demonstrating its ability to take an existing prototype back through the object function method and to simplify the product and identify redundancies in the design. The design showed that by changing a small detail, e.g., position of impact bars, it has the ability to change a failing trap into a successful trap. The lessons learnt were:

Lesson Learnt: *Possums prefer to pull on a trigger than push.*

Lesson Learnt: *Possums have the ability to extract themselves from a trap if they can use their back legs to open it.*

Lesson Learnt: *The position of the killing jaws relative to each other affects the kill time of a trap.*

Lesson Learnt: *By not having the trap attached to a fixed point, e.g., a tree, this made it more difficult for the possum to remove the trap from around its neck.*

Lesson Learnt: *The NAWAC Class A classification will be difficult to achieve for possums using a clamping of the carotid artery or wind pipe, due to their ability to resist a clamp load and the volume of air in their lungs.*

Lesson Learnt: *The designer must be involved in the manufacturing process.*

Chapter 8

Design 4: Ferret – Development and Evaluation of "Hammer"

8.1 Pre-Design Context

The Hammer trap was designed to kill ferrets and to achieve an A or B classification under NAWAC guidelines and was necessary because of the failure of other kill traps to meet these criteria, i.e., to kill in under 3 minutes (Class B). The Bulldog possum trap had killed three ferrets in less than 3 minutes, but failed to kill the fourth within the prescribed time (Table 12). The Conibear 120 trap was also tested, with different strike locations, and this also failed to achieve Class A or B (Table 12 and Figure 46). Autopsies undertaken by myself on the ferrets showed the windpipe was extremely strong. In addition the ferret has a protective muscle around its windpipe that needed to be clamped before it could be blocked. A large rhomboideus muscle (Figure 47) protects the top of the ferret's head. Therefore, the cushioning effect of this muscle needs to be overcome before the skull can be ruptured. The ribcage is a weak area for this animal (B. Warburton, pers. comm., 2003), but it is unlikely that targeting the ribcage area would result in a trap that meets NAWAC's A or B classification, because the animal may still be able to breath beyond 3 minutes. Given the above analysis it appears the throat is the most likely target for a successful static clamp kill. Thus, to gauge the strength of the ferret's throat a load of 70 kg was applied via a 6 mm bar for 3 minutes. This load is far beyond the limits of animal traps, and was still insufficient to kill the ferret.

Table 12. NAWAC Classifications for Bulldog and Conibear 120 for Killing Ferrets (source: Manaaki Whenua Landcare Research Ltd)

Trap	Strike location	Animal 1 (min:sec)	Animal 2 (min:sec)	Animal 3 (min:sec)	Animal 4 (min:sec)	Animal 5 (min:sec)	NAWAC guidelines classification
Bulldog	Neck	2:50	2:47	2:38	3:87	>5:00	Class C
Conibear 120	Neck	2:30	2:50	>5:00			Class C
Conibear 120	Chest	1:00	1:39	>5:00			Class C

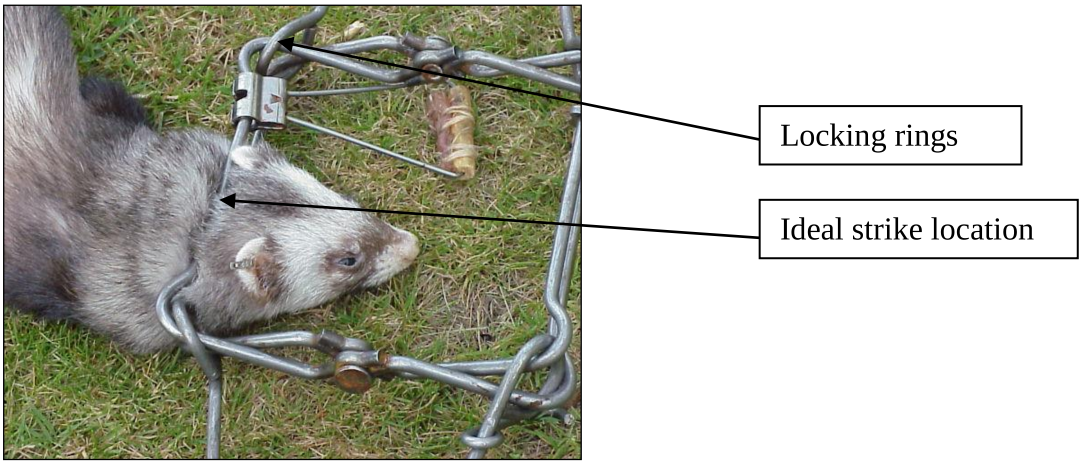


Figure 46. Ferret caught in Conibear 120 trap (modified photo from Nick Pouto)

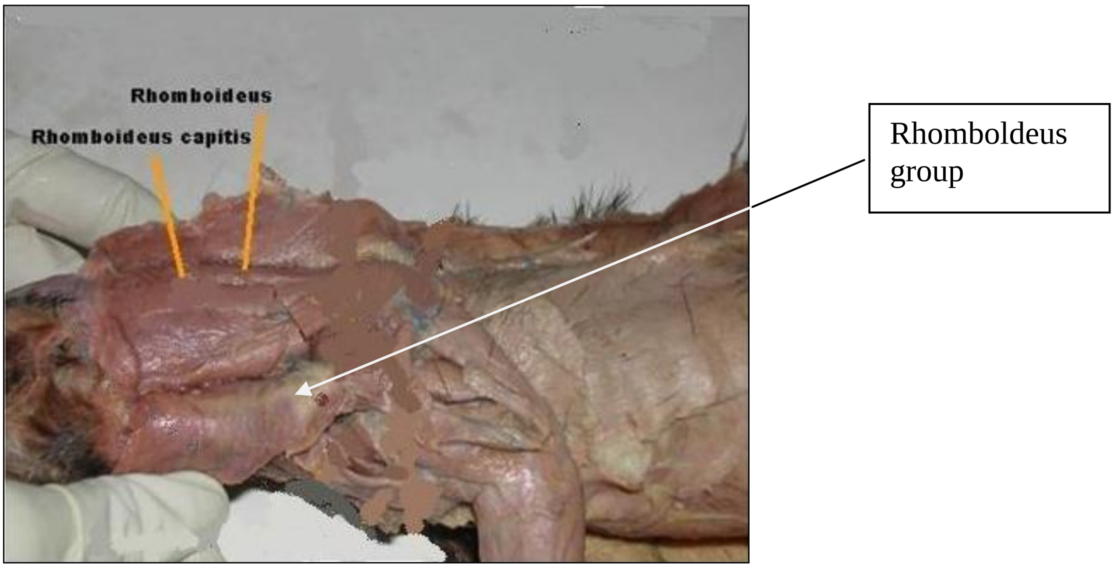


Figure 47. Ferret head, neck and shoulder anatomy (modified by removing all other muscle names except Rhomboldeus group (Clayton & Lenox, 2006)

Thus, based on the trial findings and muscular composition and characteristics of ferrets, it is unlikely they can be humanely killed with a static clamp within acceptable NAWAC standards, because of the very large force required.

8.2 Need Analysis

To design a trap that can kill ferrets to the highest classification (Class A/B) under the NAWAC guidelines.

Need Statement: *To design a ferret trap that will kill ferrets with the highest NAWAC classification*.

8.3 Concept Research Techniques

A patent search was conducted to investigate traps that have a very low trigger force yet release a large amount of energy, e.g., gas powered electrical or alternatively the application of poison. The use of large mechanical traps was precluded from the search as the preliminary work from the Bulldog trap showed that a clamping force well in excess of 20 kg using a 1.6 mm impact bar was not successful for ferrets. A meeting was held with DOC staff from Macraes Flat in Central Otago, as they have severe problems with ferrets, to find out how they perceive the behaviour of ferrets towards traps. Insight into the behaviour of ferrets was also achieved by talking to Dr. Justine Ragg, whose PhD research investigated ferret behaviour (Ragg, 1997) and these discussions led to the requirements outlined in section 8.4.

8.4 Design Requirements

The design requirements for the prototype Hammer trap were to:

- be able to kill ferrets, rats and stoats as opposed to just one species
- have a less than 10 kg setting requirement by the user (because a mechanical kill trap design for ferrets may be physically difficult to set)
- pass the NAWAC guidelines and obtain an A/B classification
- weigh less than 1 kg
- have a selling cost of around $40
- ensure operator safety when setting.

8.5 Concept Configuration Model

From the concept research it was evident that the possibilities for killing the ferret were to use CO_2, electrocution, a poison applicator, a gas-powered piston and a detonator or a captive bolt powered by a Ramset® charge. Conversations with DOC and Target Pest's Christchurch staff indicated that what they really wanted to do was to put a semi-automatic 0.22 above the bait and shoot each animal. The problem with doing this was that this would be illegal under the

Arms Act 1983. There was the possibility of using a high-powered air pistol, which has similar ballistic characteristics to the 0.22 rifle. However, on contacting the New Zealand Police Firearms Head Office I was told that the Police were moving quickly to ensure that these pistols also needed a firearms licence to own (Sergeant M. Green, pers. comm., 2010). There was an allowance for a person to use a humane killer, but it was not acceptable to leave it in the open. This became an interesting problem, because if a person does not have a firearms licence, then the Arms Act 1983 does not apply to them. Consequently, a person *without* a firearms licence could leave a humane killer in the wild, but a person *with* a licence could not. A captive bolt-powered system was the chosen concept. Many of the other concepts would have satisfied all the design requirements except the allowance for the selling cost of the trap. For example, the use of CO_2, a poison applicator, and electrocution all require a metering system which is expensive to achieve. In comparison, the cost per kill for a Ramset® charge is 15 cents and the energy source has already been metered.

No license is needed to purchase Ramset® blanks, as they do not have an attached projectile. A detonator as used in electronic mole traps (USPAT 4213265) was considered. However, the aluminium casing during detonation would be considered a projectile and therefore contravene the Arms Act 1983 if left in the field unattended.

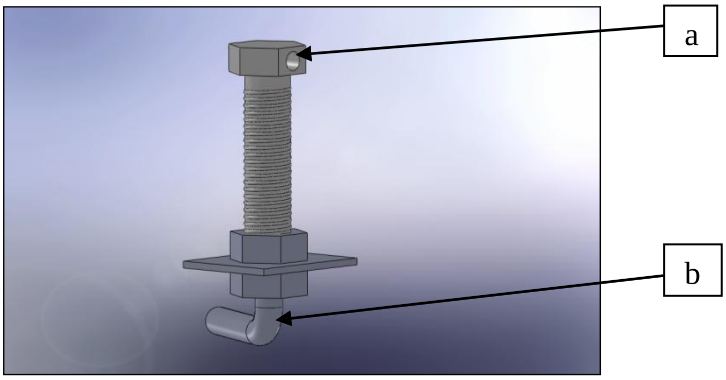
8.6 Concept Design

The Ramset® charge strength ranges from white to black. White charges are capable of driving a 4 mm nail into a piece of wood and black is capable of driving a 10 mm rod into concrete or steel.

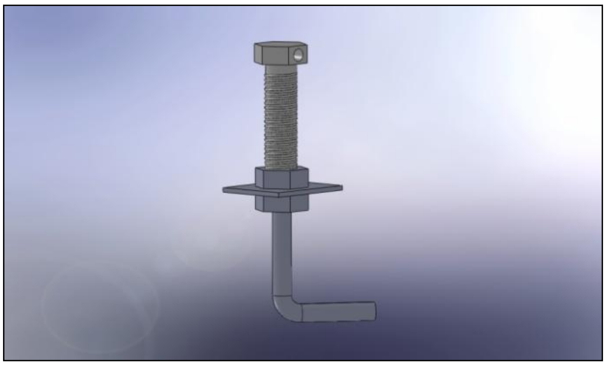
The lowest blank charge would be used in the proposed trap, and if more power was required, it would be a simple matter of using a higher-value blank. The outside casings of the blanks are all the same; the only difference being the amount of powder inside. Increasing the charge has no effect on the triggering force required. The charges are triggered by a rimfire (retrieved, February, 2007, from: www.wikipedia.org/wiki/rimfire), as are many small calibre bullets.

A bolt drilled vertically with a horizontal intersecting hole (a) (Figure 48i) was used in an effort to satisfy the design issue of trying to attach the charge chamber to the body of the trap. The bolt provided all three functions:

- to act as a charge chamber (to hold the blank)
- to have a charge chamber for the impact rod (b)
- to connect the charge chamber to the trap body.



i) Impact rod in retracted position



ii) Impact rod in fired position

Figure 48. Drawing of bolt and impact rod (Source: Ian Domigan)

There was concern for operator safety because the bolt needed to be completely captive within the trap when fired. Accordingly, a 75 mm x 3 mm box section was used as the frame. The bolt was secured inside the frame, prevented from escaping the trap, as the firing chamber was bolted to the top face and the bottom face retained the impact rod. The Ramset® charge trigger was a spring-powered impact bar with a sharp wedge hitting the rim. This was the same type of firing system as used in a Gevarm machinegun. The reason why this firing system was important is that when a rimfire pin system was tested there was always damage to the side of the Ramset® holding chamber if the trap was dry-fired. However, this did not occur when a Gevarm firing system was used, as the impact was spread across the entire face of the casing.

The firing arm would be powered by springs that were released when an animal pushed on a push plate (Figure 49). This allowed the firing arm to swing freely and strike the Ramset® blank. The explosion would power the impact rod downwards. The problem was that the charge needed to be retained as it would expel itself under back pressure. This would pose a major danger to any person present when the trap fired, as they could be struck by the ejected brass Ramset® case.

The other major problem with the trap was that the recoil of the firing arm caused permanent deformation of the springs.

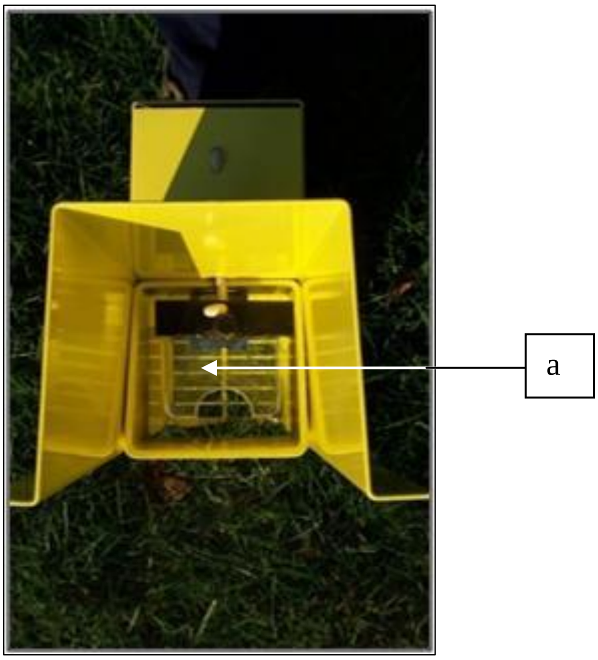


Figure 49. Looking down the Hammer trap at the plastic push plate (a) (source: Ian Domigan)

8.7 Test Results

Even with these design problems the Hammer trap was tested as it was important to confirm that the trap design could achieve a Class A status under the NAWAC guidelines. The trap did achieve Class A status for ferrets (Table 13), stoats (Table 14) and rats (Table 15) (Figure 50).

Table 13. Outcomes of Ferret Captures in the Hammer Trap. Times to loss of consciousness can only be given as maximum times, as it took the observer 30 seconds to reach and monitor the captured animal. All captured animals had lost their heartbeat within 3 minutes of capture (Data courtesy of Manaaki Whenua Landcare Research Ltd).

Weight (kg)	Sex	Palpebral reflex (min : sec)	Strike location
0.81	Female	<0:30	Head
1.1	Male	<0:30	Head
1.07	Male	<0:30	Head
0.99	Female	<0:30	Head
0.9	Female	<0:30	Head
0.82	Female	<0:30	Head
0.85	Female	<0:30	Head
0.96	Female	<0:30	Head
0.76	Female	<0:30	Head
0.62	Female	<0:30	Head

Table 14. Outcomes of Stoat Captures in the Hammer Trap. Times to loss of consciousness can only be given as maximum times, as it took the observer 30 seconds to reach and monitor the captured animal (Data courtesy of Manaaki Whenua Landcare Research Ltd).

Weight (kg)	Sex	Palpebral reflex (min : sec)	Heart stop (min : sec)	Strike location
0.240	Male	<0:30	2:09	Head-neck
0.258	Male	<0:30	2:10	Head-neck
0.291	Male	<0:30	2:30	Head-neck
0.285	Male	<0:30	2:47	Head-neck
0.212	Male	<0:30	2:20	Head-neck
0.234	Male	<0:30	2:42	Head-neck
0.285	Male	<0:30	3:28	Head-neck
0.295	Male	<0:30	2:13	Head-neck
0.244	Male	<0:30	2:48	Head-neck
0.321	Male	<0:30	2:35	Head-neck

Table 15. Outcomes of Rat Captures in the Hammer Trap. Times to loss of consciousness can only be given as maximum times as it took the observer 30 seconds to reach and monitor the captured animal. All captured animals had lost their heartbeat within 4 minutes of capture (Data courtesy of Manaaki Whenua Landcare Research Ltd).

Weight (kg)	Sex	Palpebral reflex (min : sec)	Strike location
0.298	Male	<0:30	Shoulders-chest
0.254	Female	<0:30	Shoulders-chest
0.247	Female	<0:30	Shoulders-chest
0.155	Female	<0:30	Shoulders-chest
0.163	Male	<0:30	Neck-shoulders
0.153	Female	<0:30	Head-neck-shoulders
0.119	Female	<0:30	Shoulders-chest
0.365	Female	<0:30	Skull-neck
0.337	Male	<0:30	Rear of head to shoulders
0.265	Female	<0:30	Rear of head to shoulders

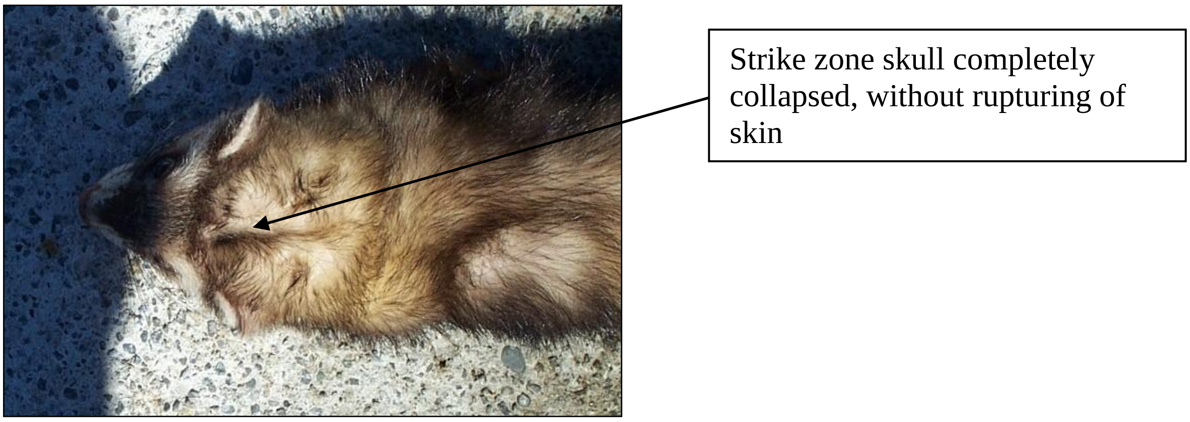


Figure 50. Ferret's head after being struck by the Hammer trap showing little visual damage (source: Ian Domigan)

Important design faults identified during humaneness testing were the Ramset® casing flying freely from the trap, and springs being stretched due to recoil.

A redesign was conducted with the major concern being operator safety, now that the trap had achieved the NAWAC guideline classification. A metal cover was added to the trap to act as a charge retention device and trigger setting system (Figure 51).

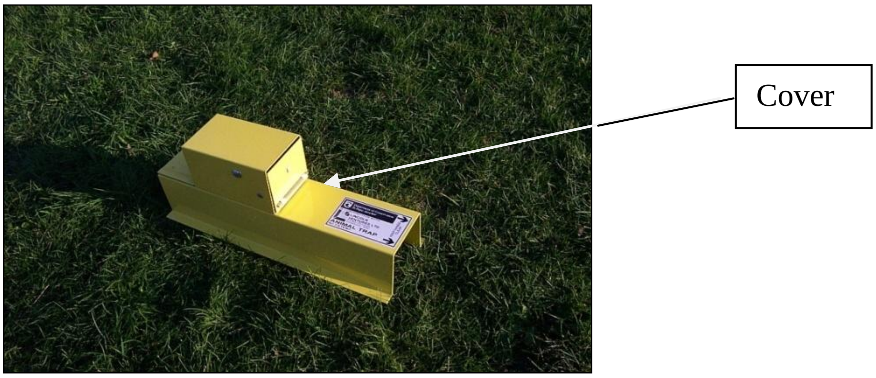
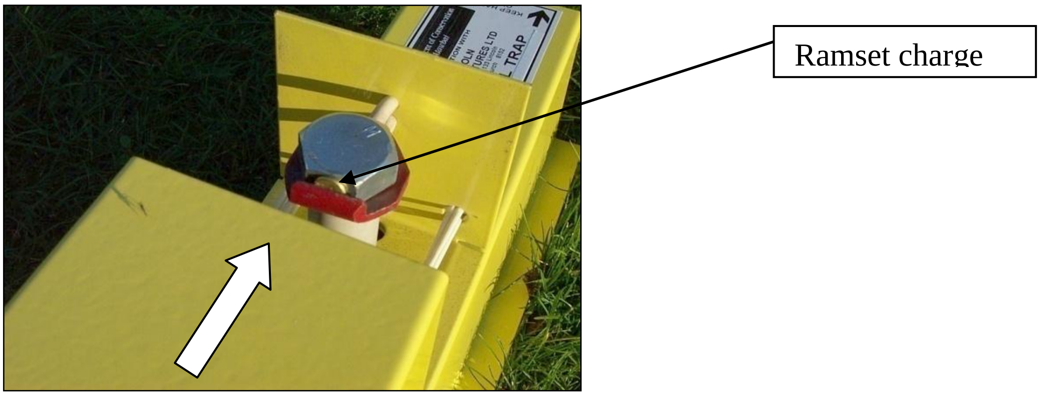


Figure 51. Hammer trap with cover closed (source: Ian Domigan)

When moving back the cover case, the action would drag the trigger impact arm down and the trigger impact arm could not impact the charge until the cover was in the closed position. The complete cycle for setting the trap is shown in Figures 51a and b.

a) Here the cover has been slid back, thus loading the impact arm



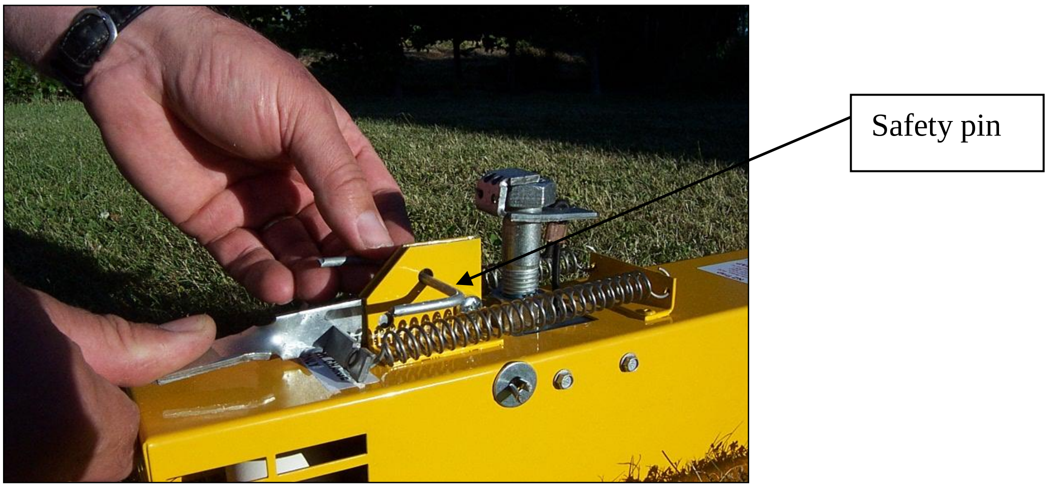
b) The Ramset® charge having been replaced, the trap cover is then slid back into position (Figure 51)

Figure 52. Setting procedure for Hammer trap (source: Vera Domigan)

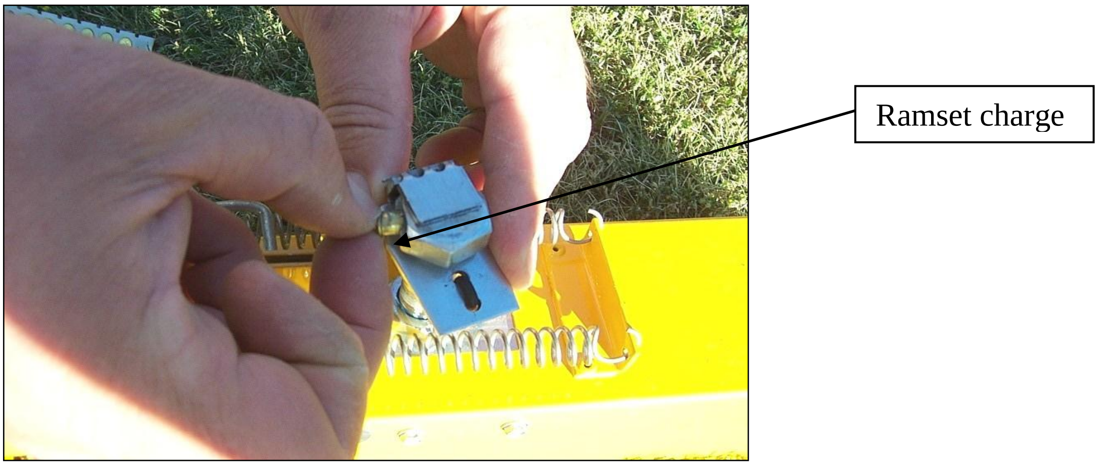
The handler safety aspect was now satisfied and recoil damaging the springs was addressed by using stretched rubber rings, which absorbed the recoil without deforming. The use of coil springs in semi-automatic and automatic rifles was also a possibility, but these springs are generally greater than 200 mm (R. Tiffen, pers. comm., 2004).

A trial on a rat was conducted without an impact bar, using the high-powered black Ramset® charge. The percussions blew away half of the rat's head, but the rat was still able to survive past the 3 minute time frame. Consequently, this approach would be classified as a Class C trap for rats under NAWAC guidelines.

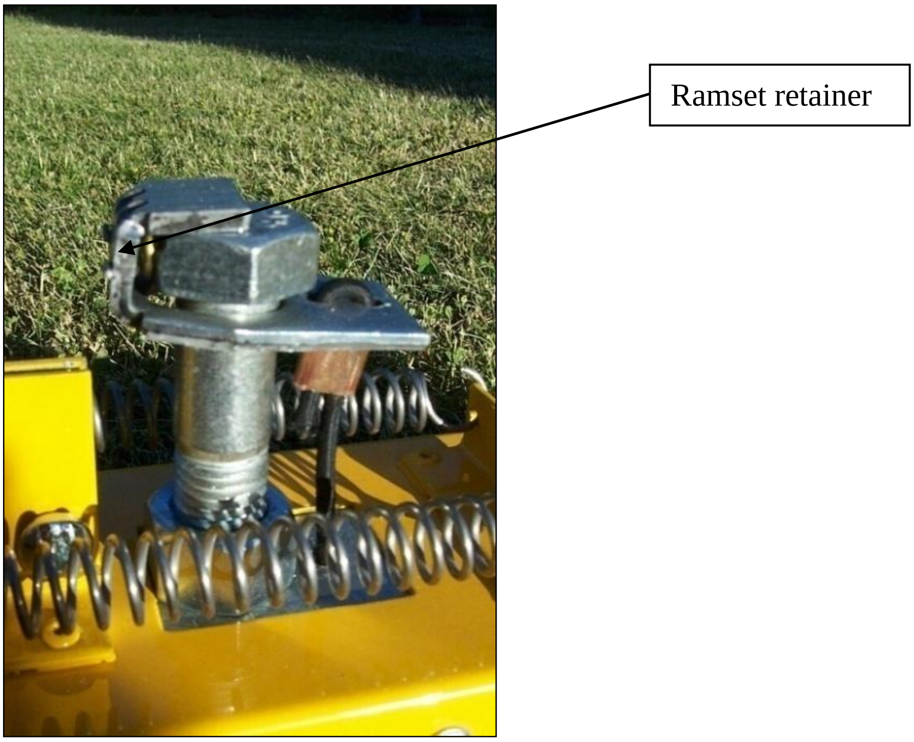
The trigger mechanism is based on a two-trigger system. The primary trigger, activated by the animal itself, releases a spring-powered arm; this then activates the charge. Encouraged by the trap passing the NAWAC guidelines the trigger system and a new charge-retaining system was designed (Figure 53a-d) and a field trial conducted (see section 8.8).



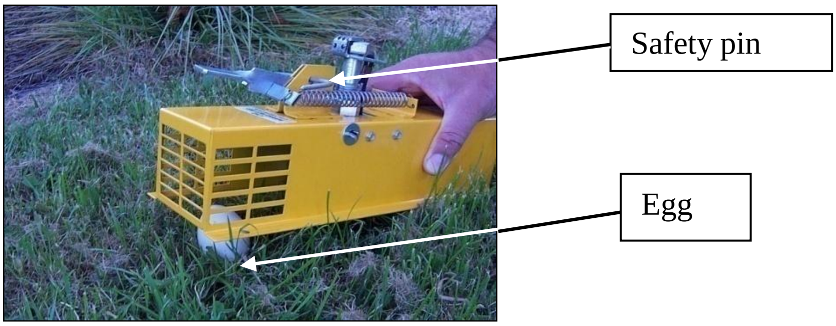
a) Trap trigger arm loaded and safety pin in place



b) Ramset® retainer swivelled and charge pushed in place



c) Blank retainer snaps back into position (firing pin thin wire in retainer)



d) Trap placed over bait and then safety pin removed and the trap is then armed.

Figure 53. Modified Hammer trap as used in field trial (source: Vera Domigan)

The Hammer trap is very different from most other traps in that it targets ferrets' heads, rather than their neck and chest area. The design could not proceed to commercialisation until a field trial was conducted. Another advantage was that the trap could also kill rats and stoats in the same configuration.

8.8 Field Trial

A field trial of 40 modified Hammer traps was conducted in the Rotorua area, targeting ferrets. It was led by Animal Health Board Incorporated – they hired contractor Phil Cummins.

The traps failed to kill any animals despite having been triggered. Larger springs were then added to the traps to ensure the Ramset® charges would fire, but the traps still failed to kill any animals. Misfiring was a serious issue. It was caused because charges absorbed moisture in the field and the powder became wet and would not fire. There was also concern expressed by Phil Cummins that the entry opening size was too small for ferrets as they encountered many large ferrets of 4-5 kg and at least a 100 x 100 mm entry would be required. He also considered that the push trigger was not as effective as a treadle trigger.

The field trial showed that the size of the opening and a system of ensuring the charge does not absorb moisture; which was addressed by the use of Vaseline or wax to prevent moisture uptake. This was not pursued, as it was expected that the electric Hammer, detailed in chapter 10, would supersede the original Hammer trap. The design flow chart for the Hammer is shown in Figure 54.

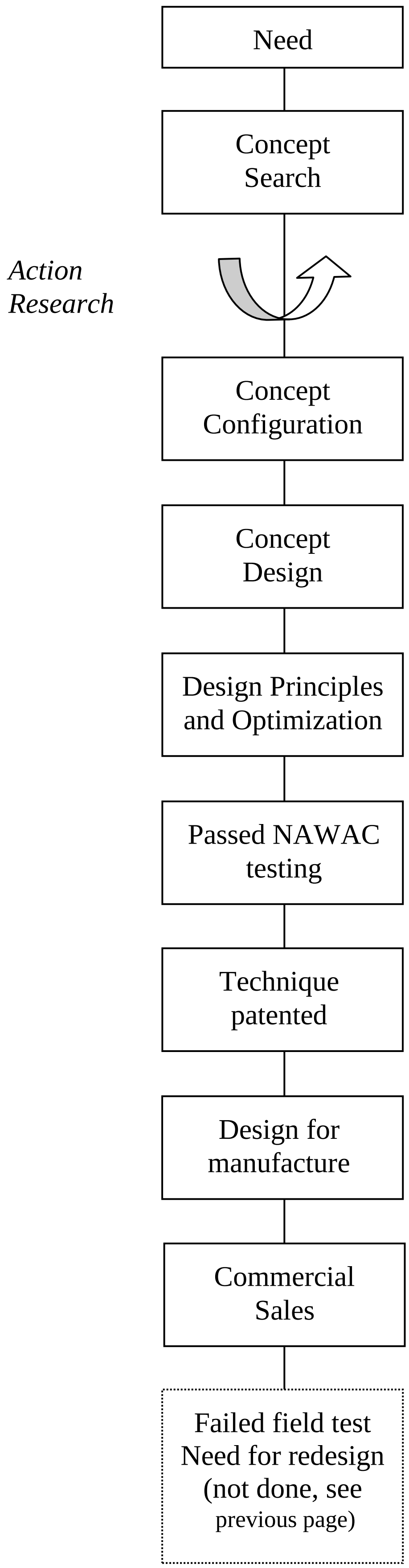


Figure 54. Design flow chart for "Hammer"

8.9 Design 4 Conclusions

The Hammer trap concept had a tremendous advantage over other traps in that a variable amount of impact force independent of the trigger pressure can be achieved. Again the issue of a push trigger in field trials appeared to be lowering the catch rate and there were issues of trap misfire that were addressed by coating the blanks in Vaseline or wax to prevent moisture uptake. A blank was then left submerged in water for two weeks after having these coatings applied and fired correctly.

Lesson Learnt: *A Class A trap is possible for ferrets, stoats and rats in a single trap configuration.*

Lesson Learnt: *A Ramset® power tool blank provided an excellent source of variable power.*

Lesson Learnt: *The entry of the trap needed to be increased from a 75mm square*.

Lesson Learnt: *Operator safety needs to be addressed as traps become more powerful.*

Chapter 9

Design 5: Ferret, Possum, Cat, Stoat, Hedgehog - Development and Evaluation of "Blitz"

9.1 Blitz Overview

The Blitz trap was designed to catch ferrets, possums, cats, stoats and hedgehogs. The cats, stoats and hedgehogs are considered to be bycatch as the trap was to specifically target ferrets and possums. The challenge is that these animals all have different target strike location distances from a common entry point, and consequently one trap is unlikely to be humane for all of the species. For example, the strike distance (neck) for a possum is 130-150mm (section 7.2) from the bait whereas the strike distance for a stoat targeting the head is 30-40mm (section 4.11). Possibly the baiting of the trap could limit the entry, e.g., a stoat would not be interested in a piece of apple, but a possum would. The cost for humane testing on all species would be expensive, approximately $10,000 per species (based on what was paid to Manaaki Whenua Landcare Research Ltd for conducting the pen trial). This possibly makes this trap uneconomic due to the volume of sales required to just recover the cost of NAWAC's guidelines testing procedure for multiple species. It was decided that once the Blitz trap was designed, it would be field tested on possums as the kill thresholds for a trap are known (Warburton & Hall, 1995). The Blitz trap would then be classified for the NAWAC guidelines using ferrets, as they had shown themselves to be difficult to kill humanely due to the strength in their necks.

9.2 Trap Requirements

The Blitz trap needs to catch cats, possums, ferrets, stoats and hedgehogs in the same trap configuration. The possum and cat will be the controlling animals for trap size as those animals need to place their heads in the trap. The Blitz trap will need to:

- be used for multiple species
- be compact: 300 mm (L) x 150 mm (W) x 175 mm (H)
- have a self setting trigger

- be set by pulling on a string
- have a trigger that can be set in both horizontal and vertical positions
- be able to be used on ground or vertical set
- be constructed of rust-resistant materials
- have as slim a killing bar as possible, to allow for good throat penetration, particularly on ferrets
- sell for $30–$40 (with a manufactured cost $15-$20).

9.3 Need Analysis for the Blitz Trap

To develop a trap to kill cats, possums, ferrets, stoats and hedgehogs that can be used in both horizontal and vertical sets, all in the same trap configuration, because this will not require the purchasing of separate traps for each species.

Need Statement*:* *To develop a multi species trap for ferrets, possum, cats, stoats and hedgehogs.*

9.4 Research Techniques

From previous work, particularly in developing stoat (chapters 4 & 5) and possum traps (chapter 7), I gained a good understanding of stoat and possum behaviour towards traps. However, I had little understanding of ferrets, cats and hedgehogs. To gain more insight into how cats behave towards traps, I observed testing of the Steve Allen (DOC Whangarei) trap (a double sprung Conibear trap with the spring size increased). This testing was operated under NAWAC guidelines by Manaaki Whenua Landcare Research Ltd. To better understand hedgehogs, I met with Akaroa DOC staff that catch more than 200 hedgehogs each year (R. Burly, pers. comm., 2004). Connovation, who were marketing the Bulldog trap and intended to market the Blitz also had input (Steve Hix, Connovation Ltd) during the concept phase through to the testing phase, to ensure that the product would meet their requirements, along with providing additional understanding of the target animals.

9.5 Concept Configuration Model

The Blitz trap would not be able to be triggered by a treadle plate, because if a treadle plate was to be used for these larger animals, the trap would have to be of similar size to a cage trap, which is well beyond the design brief. Given previous problems with getting possums (section 7.7) and stoats (section 4.12) to trigger a push trigger system, a pull trigger was chosen. The over-centre spring design (section 4.7) has the ability to set both horizontally and vertically by moving the impact bar to the over-centred position. This is essentially pointing towards a Thumper trap with a pull trigger (section 4.7) but on a larger scale to accommodate cats and possums.

9.6 Concept design

9.6.1 Treadle and Pull Trigger

The initial concept design incorporated both a treadle and a pull trigger so that smaller animals (stoats, sometimes smaller ferrets, and hedgehogs) would trigger the trap by standing on the treadle while the larger animals (cat and possum) would trigger the trap by pulling on a bait. This became a difficult trap to set and complicated to make, and was consequently not pursued.

9.6.2 Pull Trigger

The Blitz trap has a pull trigger (concept 2, Figure 27 section 4.15) and a body based on the Dominus metal body design (section 5.3), except with a solid end; as unlike the Dominus trap, no double entry is required. The trap impact arm is powered by two torsion springs. Two springs were chosen over one to balance the trap. If a single spring was used and it moved off the centre line, it would result in unbalanced forces on the trap pivots. This could bend the impact bar. The same springs were used as in the Dominus trap, as this would mean fewer parts to be ordered in the manufacturing phase. Given the extra loading on the impact bar from the two springs, friction on the pivot needed to be reduced. There is also the need to ensure that the pivot will not seize due to rusting, as the trap can stand idle for months between re-baiting and trapping an animal. Accordingly, a plastic “off-the-shelf” pivot (bush) was used.

The sides of the trap need to be as open as possible. David Hunter (pers. comm., 2004) experienced this first hand, and told me how he had personally come across “an electronic multi-kill possum trap that failed to kill possums until the side of the trap was shelled out. Then it started to kill animals”. He believed the reason for this was that “possums did not like putting their head in a tightly enclosed box”, which could account for why the Timms trap has such a large open box for the animals to enter.

The Blitz trap needed a trigger that would locate the animal centrally and stop rats from stealing the bait. Re-useable plastic baits are available that are impregnated with an alluring scent that can last more than a year (S. Hix, pers. comm., 2006). The only disadvantage with these baits is that rats tend to remove them from traps. This was to be resolved by making it impossible for the bait to be slid off the baiting bar when the trap is sitting on the ground or tree mounted (Figure 55). To replace the bait the trap needed to be triggered. When the trap is turned upside down the trigger arm swings below the lower body of the trap allowing for baiting (a).

Figure 55. Baiting the Blitz trap (source: Vera Domigan)

The impact bar stop (b) of the first Blitz trap constructed was too close to the bottom of the trap. When the trap was set vertically, the animal’s head had to be pushed more than 30 mm into the trap before being wedged between the impact bar (c) and stop bar. Much of the impact momentum was lost by moving the animal’s head rather than providing the swift impact from the impact bar. To remedy this problem, the impact bar stop was moved to a higher position (Figure 56). Also, the front of the trap was made larger to accommodate the desired 100 mm clearance above the repositioned impact bar.

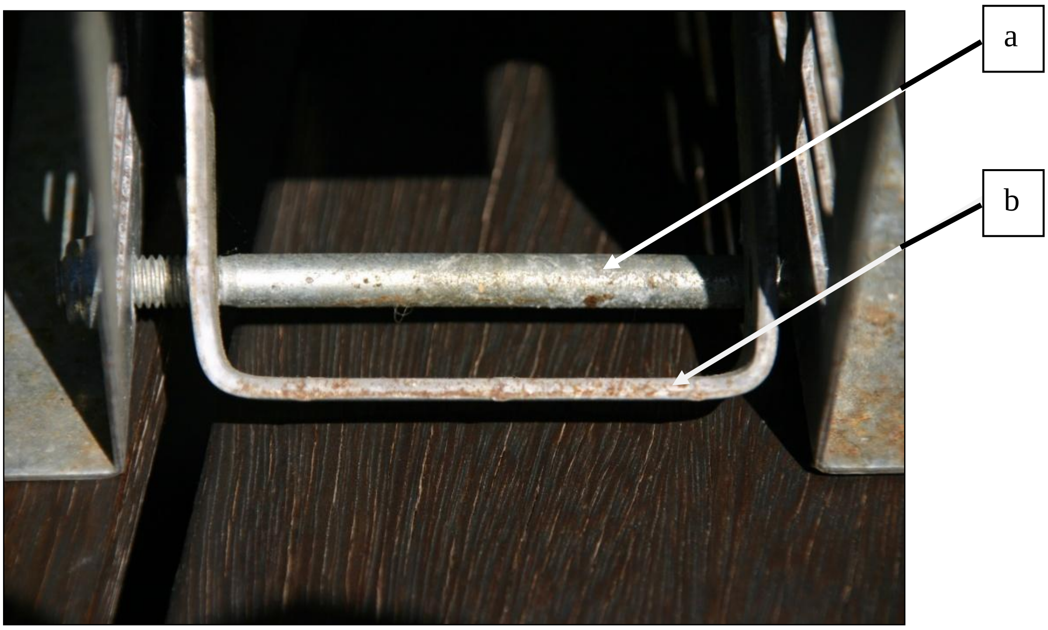


Figure 56. Location of bottom impact bar (source Ian Domigan)

The bottom bar (a) needed to be as slim as possible, yet capable of withstanding the impact of the impact bar (b) without damage if dry-fired. The thinner the bottom bar, the better the penetration into the animal's neck and the better the chance of blocking the windpipe or carotid artery. The solution was to avoid the need for the bottom bar to take the dry-fire impact, by having two bolts through each side to absorb this load (see (a) - Figure 57). This allowed the impact bar (b) to be very slim, at just 1 mm.

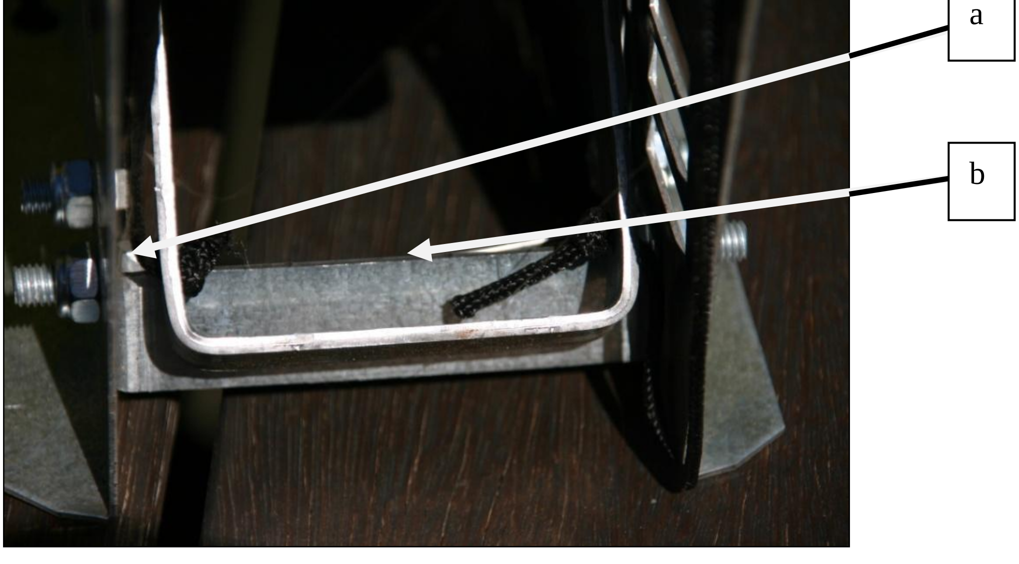
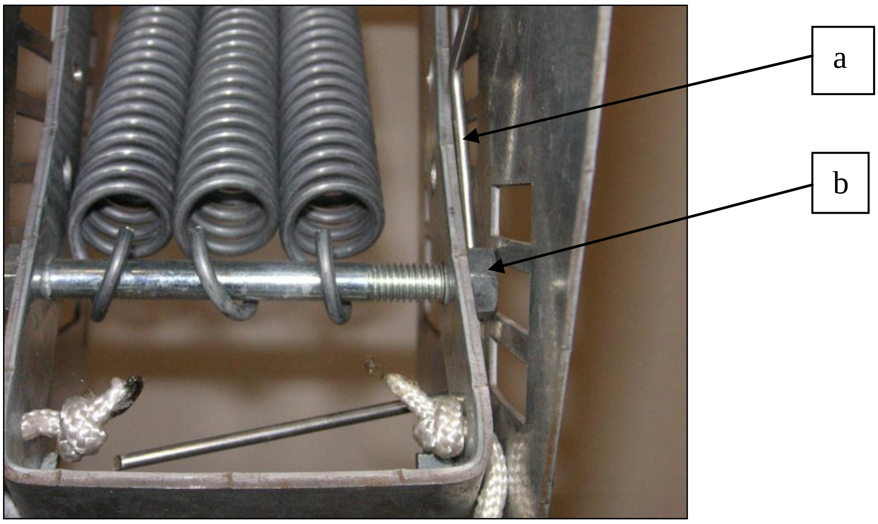


Figure 57. Modified impact bar (source Ian Domigan)

There were problems with the cross pin on the Thumper trap's impact bar coming out. This problem was resolved using a steel glue (Assembly Loctite®).

However, given the additional loads the springs of the Blitz trap were going to apply, any bending in this pin could easily cause it to come free from the impact bar. A bolt was chosen as if overloaded it would bend, deforming the sides of the impact bar. This bolt head also provided a means to trigger the trap by locating the trigger arm (a) (Figure 58i) under the head of the bolt (b) (Figure 58i). This also allowed the trigger to self-set (Figure 58ii –iii) when the impact arm was pulled up, as the springs went over centre. The bolt head (b) and the pivot hole for the trigger arm were located to provide a 4:1 leverage when an animal pulled on the trigger arm (a).



i) Trigger position

ii) Pull on string (trigger sets automatically)

iii) Place string on top of trap

Figure 58. Setting procedure for the Blitz trap (source: Ian Domigan)

The body of the trap needed to be as open as possible, so the side of the trap was shelled out. As Table 16 shows, the Blitz with the pull trigger has the highest rating. Unlike the Timms trap, it can trap hedgehogs and stoats. At 200 mm above the ground, the Timms' trap entry hole is also too high to allow access for hedgehogs.

Table 16. Blitz Prototype Evaluation Table (see section 3.5.7)

Design Criteria	**Treadle and pull trigger**	**Pull trigger**	**Timms trap**
Multi-species	1	1	D
Compact: 300 mm(L) x 150 mm(W) x 175 mm (H)	1	1	A
Self-setting trigger	-1	0	T
Set by pulling on a string	0	0	U
Trigger able to be set in horizontal and vertical positions	-1	0	M
Trap able to be used on ground or vertical set	1	1	
Trap constructed of rust-resistant materials	0	0	
Killing bar as slim as possible to allow for good throat penetration	1	1	
Total	**2**	**4**	

Note: The cost of the chosen prototype is only able to be evaluated after the manufacturing phase is complete.

9.7 Design Principles

The major problem with the Blitz pull trigger design is the impact bar protruding from the trap body (not shown in figures). Accordingly, an animal merely placing their paw on the top of the trap would most likely set it off. After observing possums and ferrets entering traps I noticed that they nearly always placed a paw on the top of the trap, perhaps investigating this 'new thing' in their environment. The trap was therefore redesigned to allow the impact arm to come within the protective bounds of the trap body and yet still be able to be set by pulling a string.

The trigger was made of 3 mm stainless steel rod bent to use the head of the bolt in the impact bar as the leverage point for the trigger to move the impact bar to the over centre position. This allowed for a force reduction of 8:1. Stainless steel was chosen as it is corrosion resistant. The trigger pivot was a 4 mm hole in the trap body with 20 mm bent at 90° to hold the trigger in place. The trigger was attached through a single hole in the trap body and being sandwiched between the impact bar and the trap body acted as a reliable guide for the trigger arm. There was quite a variation in the trigger pressure required. This was because the triggers and impact bars for the traps were hand bent, which allowed this variation to occur. For this reason an adjustment screw was added that would allow the trigger to be set to whatever level the end-user required.

The trap width was designed around the impact arm spring retaining bolt. This bolt needed to be strong enough to resist the load of two springs. It also needed to be close-fitting enough to ensure that the bolt head or nut did not scrape the inside of the trap; and that the trigger arm could not pass. As unmodified standard bolt widths were intended to be used, the width of the trap was defined by the bolts available. Experience with the development of the Bulldog trap proved that an entry width and trap height of 100 mm was successful for catching possums.

The position of the impact arm retaining bolt was defined by the overall length of the trap. This was because the spring load (20 kg) was the load the Bulldog trap required to kill possums (section 7.6), and the springs used in the Blitz had been preselected to minimise trap components. From my experience with the Thumper I knew that the spring deflection at 10 mm clamp would result in a 20 kg load. Consequently, the over-all spring length is known, and this extended length located the position of the impact arm spring retaining bolt with respect to the rear of the trap.

The Blitz trap was modelled in SolidWorks® which also gave the ability to draw the flattened layout pattern (Figure 59).

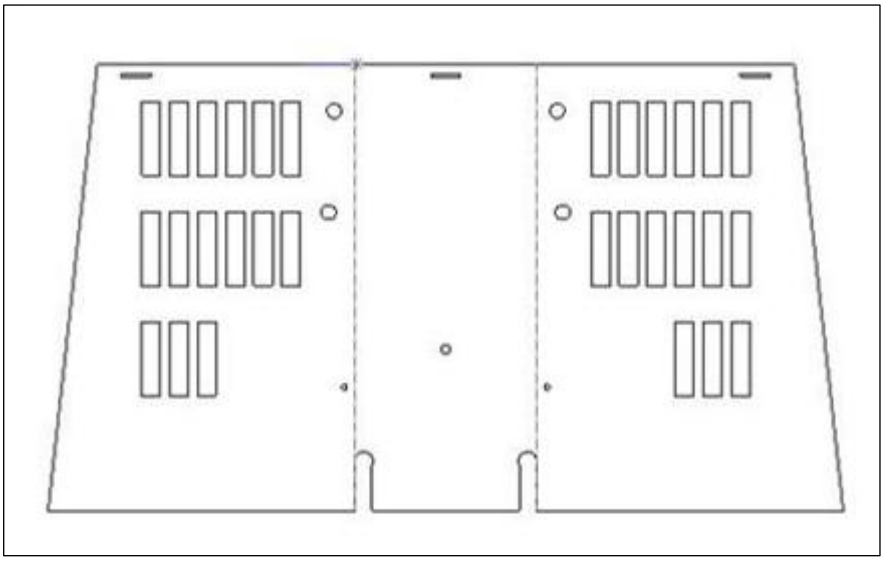


Figure 59. Blitz in flattened layout form

9.8 Manufacturing Design Principles

The Blitz trap was designed to be punched from a flat sheet using a CNC turret punch, as these machines can make complicated shapes without specialised tooling. The SolidWorks® model was downloaded via a conversion programme (COSMOSWorks®) to create the machine code. The company used to access these products became insolvent halfway through the process, and it proved difficult to gain access to similar machines as manufacturers wanted large production runs rather than one-off prototypes. This meant long frustrating wait times. Consequently, I did much of the manufacturing work myself to ensure that the prototype and field trial traps could be developed, with a total of 50 traps produced to ascertain their ability to catch possums.

9.9 Trap Evaluation

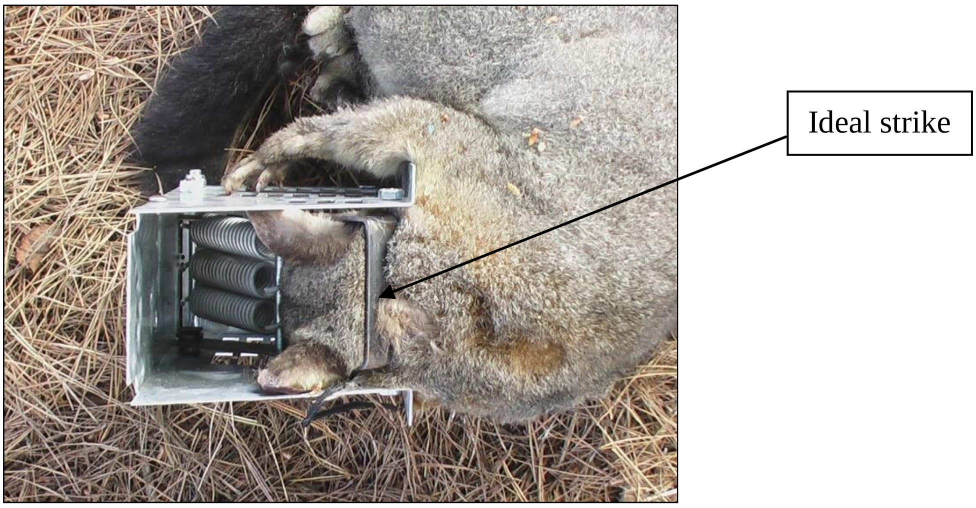
The Blitz trap had the same static clamp at 10 mm opening as the Bulldog trap (20 kg). However, the impact momentum would have been lower in the Blitz, as the over-centred spring takes longer to gain speed than a fully-extended spring with a "pull the pin" type of trigger system. The difference in these impact momenta was never measured.

The trap was field-tested in a private forest close to Springfield, and the Ashley Forest (both in Central Canterbury) by Connovation Ltd. The trap successfully caught possums (Figure

60). The strike location was consistent with that of the Bulldog trap. Given that the trigger positions and impact bar lengths were based on the Bulldog trap, this result was not unexpected. The actual trap effectiveness was never investigated as it was beyond the scope of this thesis.

The trap caught in both ground and vertical sets. When the trap was in the ground set it also caught hedgehogs and cats. No ferrets were caught. But given that of the 30 traps in the trial 27 were vertically set with only three set on the ground they were not expected to catch many ferrets (i.e., ferrets cannot climb).

a) Possum caught in Blitz when vertically set



b) Strike location just behind ears

Figure 60. Possum caught in Blitz trap and strike location (source: Ian Domigan)

The trial lasted for a month, and there were two checks at fortnightly intervals. The traps were baited with peanut butter smeared on wine bottle corks that were pushed onto the trigger arm. Cork was chosen because it was difficult for rats to interfere with, as they appear to not to eat cork (S. Hix, pers. comm., 2007). During this trial 16 possums and two hedgehogs were caught, and two traps were dry sprung.

9.10 Ferret trial

The trial was funded by the AHB, with Manaaki Whenua Landcare Research's Ltd Grant Morris conducting the pen trial to determine the Blitz classification under NAWAC. The Blitz trap had an extra spring added. Also, the spring impact bar connection bolt was moved an additional 20 mm, resulting in an increased spring load that provided a clamp of 30 kg at 10 mm opening from the usual 20 kg. The Blitz trap was set for possums with the trigger 130 mm from the jaws and a pull of 300 gm trigger pressure. The intention was to strike the animal in the ribs and hopefully penetrate into the vital organs. Successfully doing so would mean that one trigger position would satisfy the highest NAWAC classifications for both possums and ferrets. After trialing this position, the bottom impact jaw was reduced to 0.91mm from the 1.2 mm, allowing for better penetration into the rib cage.

Ferrets were individually introduced to the trap and all three ferrets were struck in the rib cage. These animals were able to survive beyond the 3 minute mark and had to be anesthetised. It was noted that it would have been impossible for the ferret to escape.
The trigger arm was then changed to target the head region by bending it so that the distance from the clamp to the trigger was 60 mm. The first three animals were struck in the head and lost consciousness (see Table 17). The fourth animal came in sideways and was struck diagonally across the head. This animal lived beyond 3 minutes and the trial was stopped.
This fourth animal appeared to not be orientated parallel to the trap, having entered at a skew angle. This was resolved by applying hazing and also restricting the entry to the trap by using a wooden covey. This meant the animal always had to be parallel to the trap upon entry. A further two animals were killed correctly. The last, a large male, was struck on the line across his eyes and went beyond the 3 minute zone. This animal also had a paw positioned under its throat, which made it difficult to fully compress the windpipe.

Table 17. Pen Trial Testing of Blitz on Ferrets

Strike location	Unconscious less than 3 minutes
1. Horizontally across ear line	Yes
2. Horizontally across ear line	Yes
3. Horizontally across ear line	Yes
4. Diagonally across eye to ear	**NO**
<u>Hazing added</u>	
1. Horizontally across ear line	Yes
2 Horizontally across ear line	Yes
3. Horizontally across eye line	**NO**

The third animal the trap was tested on after hazing was applied was a very large male ferret. This showed up the variability in strike location simply due to ferrets' varying head size. The trial was stopped as the only option for alleviating this problem was to increase the load on the springs even further. This would have made it physically difficult for the operator to set the trap.

9.11 Design Flow Chart

The design flow chart for Blitz has its roots in the design of the Thumper trap using an over centred spring (section 4.7) being the second concept design for "Thumper". The design of this trap was made easier as the concept was developed with the difficulty being in designing around existing components (springs and plastic pivots) and the design of a simply triggering system. The development flow chart for Blitz trap is shown in Figure 61.

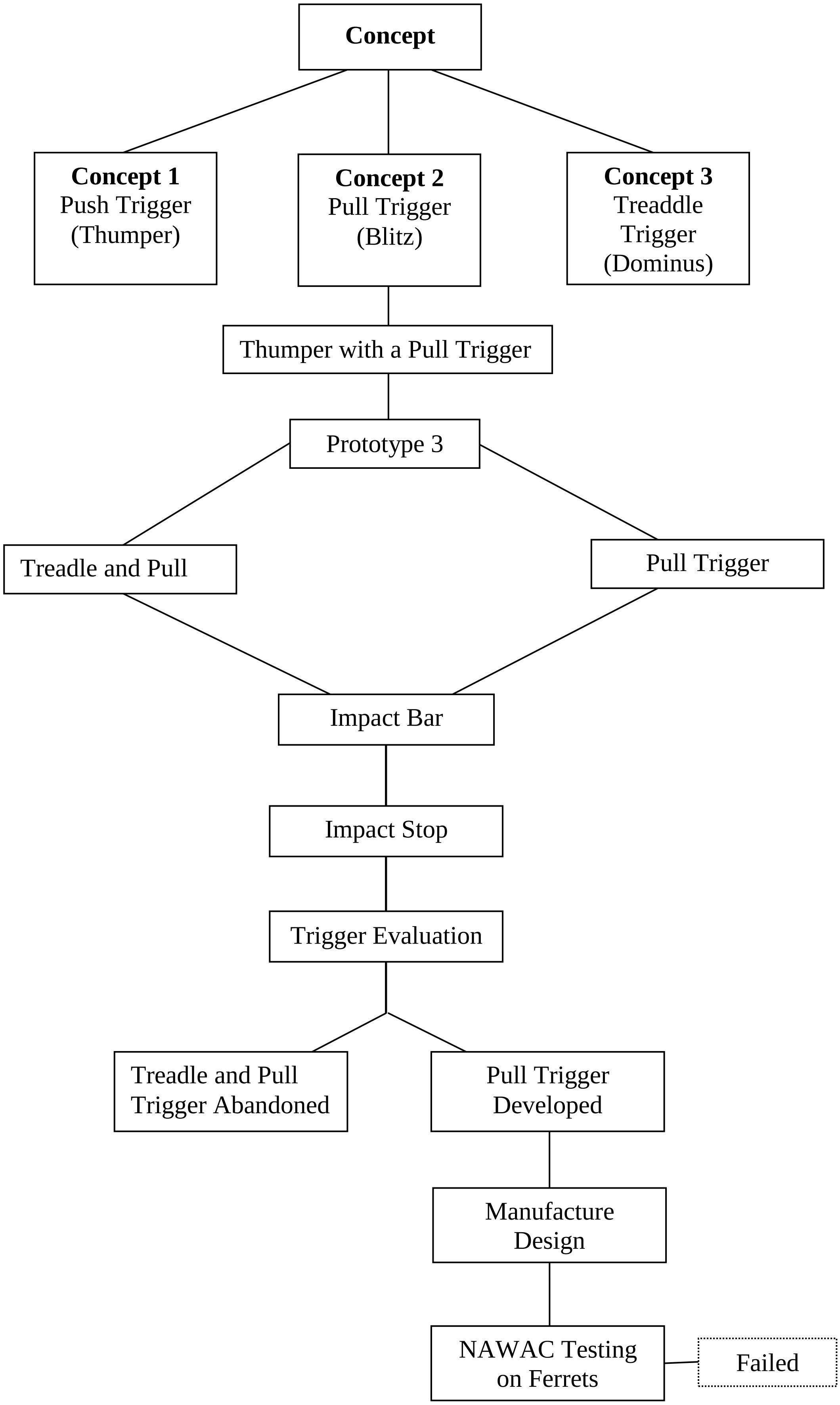


Figure 61. Design flow chart for Blitz (a continuation of the Thumper with a pull trigger, see section 4.15)

9.12 Design 5 Conclusions

The trap failed the NAWAC guidelines for ferrets, attaining only Class C status. However, given that there is no regulatory requirement for traps to be used that pass the NAWAC guidelines, the Blitz trap does provide the ability to catch multiple species.

Lesson Learnt: *A large static clamp with low impact is a poor way to kill ferrets.*

Lesson Learnt: *The head of the ferret is better to target than the ribcage to achieve a humane trap.*

Lesson learnt: *The Blitz trigger system allowed for both vertical and horizontal setting.*

Lesson Learnt: *For possums it may be a good idea to shell the side of the trap out to a greater extent thereby increasing the sense of openness.*

Chapter 10

Design 6: Evaluation of "Electric Hammer"

10.1 Need Analysis

Ferrets had proven difficult to kill by impaction in the chest and neck region (section 9.10) within the NAWAC Class A and B guidelines. The only traps that have passed for ferrets are the DOC 250 (www.predatortraps.com) and the Hammer trap (section 8.7), both of which target ferrets' heads. The DOC 250 is large, both in trap size and the box the trap sits in, which makes it difficult to place in the field. It costs $140 for a double set. Therefore the need was:

Need Statement: *To develop a light, small, cheap and humane kill trap for ferrets that meets Class A standard under NAWAC guidelines.*

10.2 Design Requirements

The design philosophy for this trap was that the trap cost would be low, but the cost of killing would be relatively high ($1–2 per kill). Normally in trapping, the cost of maintaining a trap is not significant in comparison to its initial purchase price (D. Hunter, pers. comm., 2007). The change in philosophy was because the trap needed to be powerful enough to kill the ferret and if this was done mechanically it would be of an equivalent cost to the DOC 250.

The concept required staying with the proven technique of firing a captive bolt into the animal's head as used in the Hammer trap. The trap would have:

- a cost-per-trap of $20 with a cost-per-kill of $1–2
- a sensitive trigger system
- a comparable or higher catch rate than existing systems
- a simple and operator-safe setting system
- the ability to be nested to provide multiple kills at one site
- Class A status under NAWAC guidelines.

10.3 Concept Search Techniques

A patent and literature search was conducted investigating ways of powering a captive bolt and suitable triggering systems that required very little animal input. Discussions were held (June, 2006) with the New Zealand Police (Officer Cole, Firearms officer, Wellington) on what power systems would not contravene the Arms Act 1983. Meetings were held with David Hunter (Excell) and Connovation's Steve Hix to ensure that the design requirements and proposed philosophy would satisfy the needs of the end-user and the marketing company.

10.4 Concept Configuration

Two power sources were identified: a Ramset® charge and gunpowder. Gunpowder had the advantage of not being sensitive to shock whereas Ramset® charges, being rimfired (www.wikipedia.org/wiki/Rimfire_ammunition), are sensitive to shock. Rimfire ammunition differs from centre fire in that the priming mixture is spun into the rim of the cases and is not reloadable. The cartridge is fired by compression of the rim and this sets off the primer mixture, which then reacts to ignite the powder charge.

Ramset® charges, however, will explode if thrown into a fire. One possible approach would be to electrically heat a Ramset® charge by some means to get it to explode in a controlled manner, to act as the power source for the captive bolt. As experienced with the Hammer trap, the Ramset® charge creates gas at high pressure with no need for charge containment. However, gunpowder needs to be contained to ensure that it will not simply flash when ignited. If the gunpowder is not initially constrained, then it will simply slowly burn; as opposed to being compressed, in which case it would explode.

Another approach is to use electricity to fire the charges. Electric bullets have been manufactured by Remington, called EtronX® (www.remington.com), and which are powered by a 9V household battery.

In many electric bullets there is a compound which explodes when a current is passed through them. To investigate if a power tool blank could be set off electrically, a 12V car battery was shorted out on the brass case which fired it. In this context it was due to the heat generated (short circuit) rather than the actual passage of the electrical current. To determine the current required to initiate a rimfire charge, five different manufactured 0.22 bullets were trialled.

This was done by connecting fuse wire to the bullet and noting what capacity of fuse wire was required for the bullet to fire. If too small a fuse wire was used, the wire would disintegrate before the charge was heated. It was important for fuse wire to perform two functions in the design:

- providing a means of heating the charge
- after heating the charge, breaking the electrical circuit by blowing, thereby protecting the battery.

10.4.1 Nichrome Wire Wrap Ignition

A total of ten bullets from each of the five manufacturers were tested. A 40 to 60 amp current was required to initiate the charge due to the need to produce sufficient heat. A smaller 12V, 20AH current failed to activate the charge, even though the fuse wire blew at a higher level than when the larger battery was used. This meant that a very large battery (car) was required to activate the charges as the spike current before the safety fuse blew was higher than the rating of the safety fuse (I. Woodhead, pers. comm., 2005). Therefore, a trap that used fuse wire wrapped around the top of a rimfire would require a car battery as the power source. The proposed trap would be too large and too heavy.

10.4.2 Carbon Block Ignition

A way to lower the amperage was needed. A carbon block was found to glow red hot with a current of 5 amps (12V systems). Many commercial soldering irons use this system. The ColdHeat® soldering iron uses two AA batteries as a power source to heat the tip to a temperature of 1000°C almost instantly. This is ample heat to ignite the rimfire cartridge. To determine if it was the rimfire material or the powder that was exploding, a rimfire cartridge had the gun powder removed and was heated by the carbon block. A centre fire case was filled with powder and the carbon block attached. Both systems fired, but the rimfire blank fired instantly. Therefore, it was the rimfire material that was the most susceptible to heat.

Carbon varied in its ability to conduct electricity according to its composition. The purer the carbon, the better it heats; but it also becomes more brittle and consequently harder to handle. No information was available from carbon block suppliers on the composition, resistance and heating properties of their product.

The next issue was to determine how a carbon block could be attached to the charge and yet still conduct. Many types of glue do not conduct, although most Super Glue-type products conduct to some extent. This conductivity can be increased by the addition of graphite powder. There is also silver-based glue, but this costs $70/15 cc. The graphite super glue combination had poor adhesion characteristics to the brass case, and for this reason it was not pursued.

The other issue was trying to attach a wire to the carbon block without damaging the block. A mechanical approach was used, sandwiching a spring between the carbon block and the brass case. This was also abandoned, as it was difficult to ensure a good connection between the spring and the block, and the block and the case.

The Ramset® charges appeared to be a strong concept but after much experimentation it was decided that the contacts were too difficult to achieve in the laboratory, and that this issue would only worsen with placement in the wet bush environment.

10.4.3 Nichrome Wire Ignition System

The properties and resistance values of Nichrome wire are well known (www.wiretron.com/design.html), as are the heating curves in relation to the length. The concept was to use Nichrome wire as a means of heating gunpowder to make it explode. Initial trials showed that this worked well, and the concept moved through to the prototyping phase.

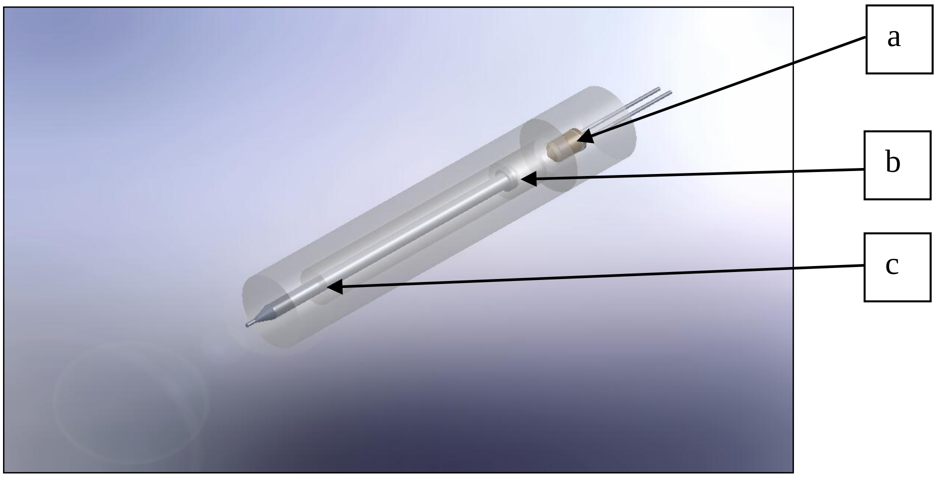
10.5 Prototypes

The material holding the Nichrome wire had to be non-conductive, otherwise the electric charge would split itself between the case and the wire. Consequently there would need to be a great deal of amperage to heat the wire. The burning rate of gunpowder varied depending upon its composition (Foteenkov et al., 1982). The higher the compression, the faster the burn rate (Ramanov, 1975).

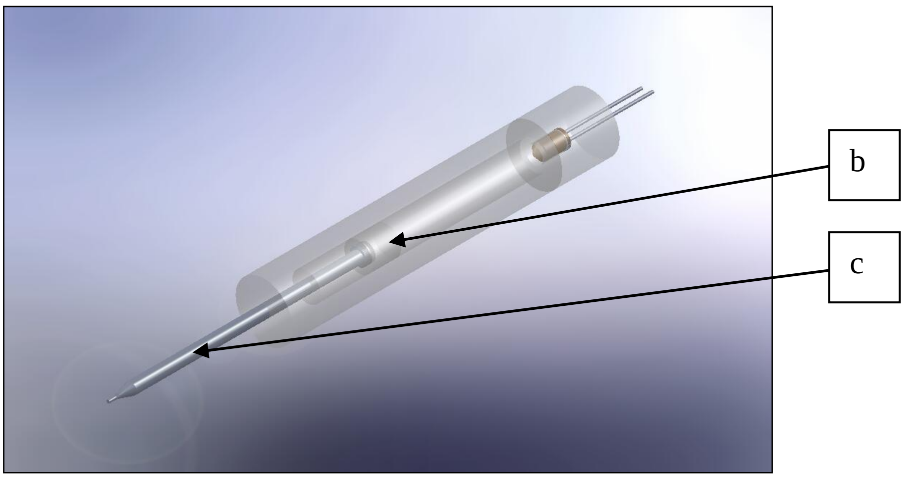
Three prototypes were made, all based on Nichrome wire as the heating source. Previous work with Ramset® charges (section 8.6) showed there were issues around gas leakage. As “agricultural fits” were desired, the chosen option was to simply increase the powder charge to allow for blow-by, while still allowing enough energy to power the impaction device. The impaction chamber was designed to be 10 mm in diameter as this was the smallest size wad commercially available.

Prototype 1

This prototype (Figure 62 i and ii) involved a self-contained chamber: (a) with a plastic wad and a plunger, (b) attached to a 4 mm nail, and (c) to hit the animal's head. The concept was that the animal would take the chamber and nail impaled in its head away from the trap. This was to save on cleaning the trap, along with the potential to have a bank of these charge heads in a magazine which would make a multi-kill trap possible.



i) Self contained charge (Not fired)



ii) Self contained charge (Fired)

Figure 62. Self-contained charge and impact rod (source: Ian Domigan)

Prototype 2

This prototype (Figure 63) involved mounting the charge system (a) in a vertical chamber, expelling gas down a vertical shaft (b) that would then power a plastic tube (c) placed over the vertical shaft downward. This system worked, but there were issues with sealing and retaining the charge, and the wires shorting out against the charge retention system.

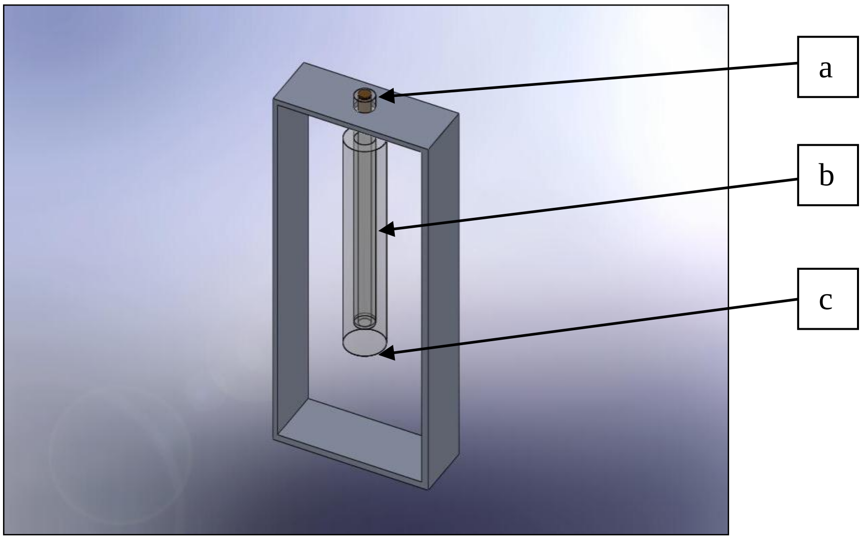


Figure 63. Vertical charge tube (source: Ian Domigan)

Prototype 3

This was a variation on Prototype 2, with the charge moved to the bottom of the plastic tube (Figure 64). This system overcame the issues of sealing, charge retention, short-circuiting and reloading as the charge tube (a) was also the impact rod and would be replaced after use. Connecting wires to Nichrome can be done either by clamping or by using a loop soldering system. This is because a conventional soldering system does not attach itself to Nichrome wire. To ensure a good contact, wires were soldered onto the Nichrome prior to the gunpowder being introduced to the charge chamber. This was also done with consideration to the safety issue of heating the Nichrome wire, which could have ignited the gun powder. The design required that the holes that the Nichrome (c) went through in the side wall of the impaction rod must be very close to the wire size, which meant using a fine (0.3 mm) drill. If these holes had too much clearance, the charge simply flashed without exploding, as there was little back pressure in the system. The powder load was measured by using grain cups (17,500 grains/kg). A wad (b) was added to ensure the gunpowder was compressed. A 20 grain cup provided enough impact and also allowed for energy loss due to leakage. The amount of energy released was never calculated, as the leakage varied from charge to charge. The impact tube was capable of fully penetrating a 13 mm piece of plywood. It was assumed that this was ample energy to crush a ferret's head (field trials later confirmed this).

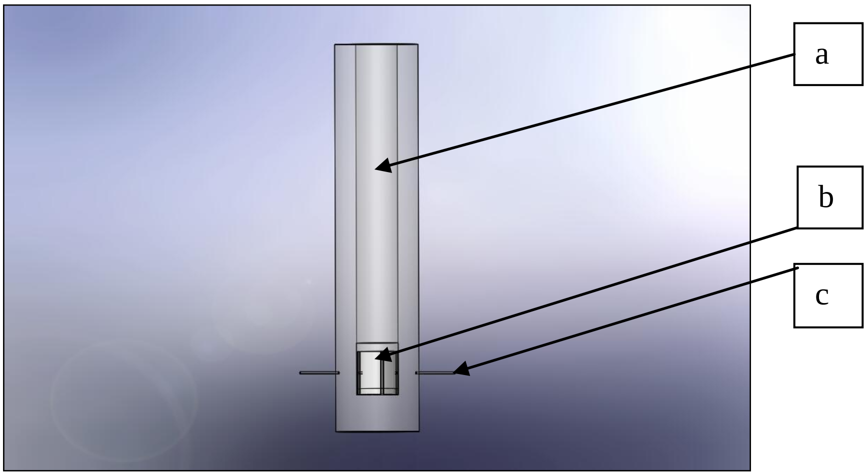


Figure 64. Explosive tube with Nichrome wire igniter (source: Ian Domigan)

10.6 Prototype Evaluation

The prototypes all satisfied the design criteria. However, in practice, the concept became constrained due to the Ramset® charges being difficult to trigger electrically using heat applied to the brass casing, as opposed to directly applying heat to the gunpowder via the Nichrome wire. The three prototypes were rated against each other (Table 18) with prototype 3 being the datum. Prototype 3 had the highest rating (Table 18), so a design based on this concept was pursued.

Table 18. Evaluation of Prototype Concepts for Electric Hammer Trap

	Prototype		
Design criteria	1	2	3
Blowback potential of firing system	-1	0	D
Ease of construction	1	0	A
Ease of loading	1	0	T
Potential for electrical short circuits	-1	-1	U
Protection for ensuring powder is kept dry	0	-1	M
Cost/kill	-1	0	
Total	-1	-2	0

Design of Prototype 3

An electrical micro-switch trigger was used. When a ferret pulled on a bait it released a micro-switch which would open the circuit (Figure 65) and allow the current to flow. A NO (Normally Open) micro switch was chosen over an NC (Normally Closed) micro-switch, because if an NC micro-switch was used, the animal could play with the trigger, making contact and then not. This of course would cause problems for the micro-switch as a DC voltage was being used, which would quickly fuse the contacts within the micro-switch.

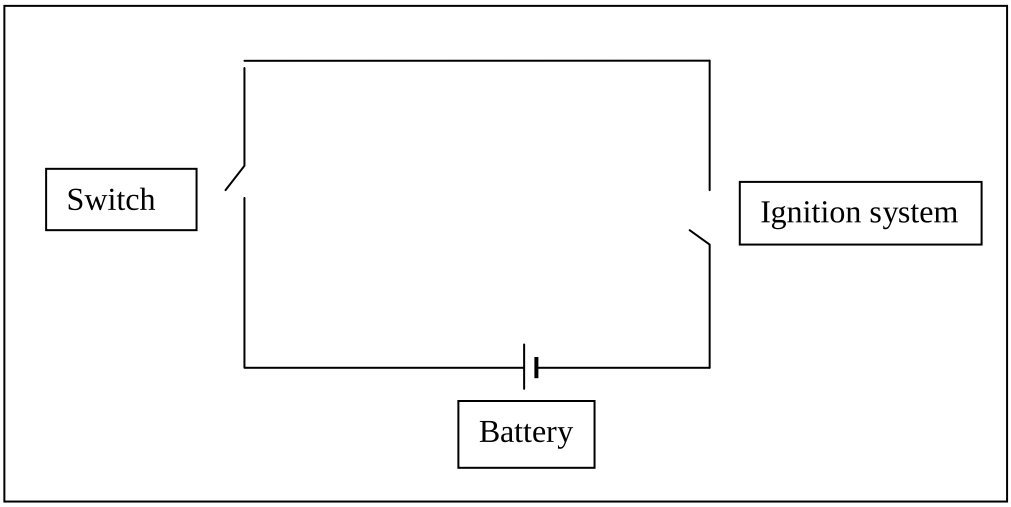


Figure 65. Electrical circuit of Electric Hammer trap

10.7 Trial of Electric Hammer

The Electric Hammer was trialled on ferrets in outside pens. A 6V 4.5 AH (Amp Hour) battery was the power source. When reviewing the videotape of trap tests there appeared to be a slight delay (0.5 of a second) between the time that the trap was triggered by the animal and the time that it fired. The ferrets were killed by the 14 mm plastic impact rod (Figure 66) (a) firing directly through their heads.

Figure 66. Ferret with impact rod in head (source: Ian Domigan)

The trial was repeated, this time using a 12V 7.5AH battery. Animals were killed with no delay noticeable. The impact rod (b) did however cause extensive damage to the wooden bottom of the trap, and a redesign was done to ensure that the impact was reacted out in a metal holding frame (Figure 67). The impact guide rod (a) was also made removable, so it could be easily changed.

Figure 67. Ferret being struck by impact rod (source: Ian Domigan)

10.7.1 NAWAC Guideline Testing of Electric Hammer Trap

The impact rod had a 4 mm rod added to the bottom to ensure that the entire trap opening was being covered by the impaction rod.

The trial was conducted by Manaaki Whenua Landcare Research Ltd and funded by AHB.

The trial was conducted indoors, with the trap placed in a fibreglass tank and the animal introduced to the box. The trap hit the first ferret perfectly but failed to kill it. The ferret was highly stunned and was euthanised. An autopsy showed major damage to the muscle on its head (see section 8.1). This muscle had separated from the skull, and small fragments of bone were noticeable. The trap had failed to achieve NAWAC's Class A or B standards.

The 4 mm rod was removed from the bottom of the impact bar and the test was restarted. The first animal was killed instantly. The trap then misfired twice when the on/off switch was turned on. The problem was found to be that the micro-switch needed adjustment, as it was not being turned off when the bait bar was put in. A second animal was killed, and then a third animal (Figure 68) triggered the trap but managed to extract itself before the impact rod fired. Camera footage revealed that the ferret travelled 60 mm in 0.15 of a second. When applying the kinematic equations for motion this gave a final exit velocity of 0.8 m/s.

Figure 68. Ferret entering Electric Hammer (source: Ian Domigan)

When observing the high-speed photography, sparks were noticed flying from the trap (Figure 69). This had not been noticed before when the trap had struck an animal. Hair was noticed to be singed about the impact rod entry point.

Figure 69. Electric Hammer fired, and sparks flying (source Ian Domigan)

10.8 Design Flow Chart

The design flow chart for Electric Hammer is shown below. The prototype 3 explosive tube was the design that was selected for NAWAC testing. The design flow chart (Figure 70) had two concepts, i.e., the use of the Ramset® charge and developing a gunpowder power source with the appropriate systems for ignition being represented in the design flow chart.

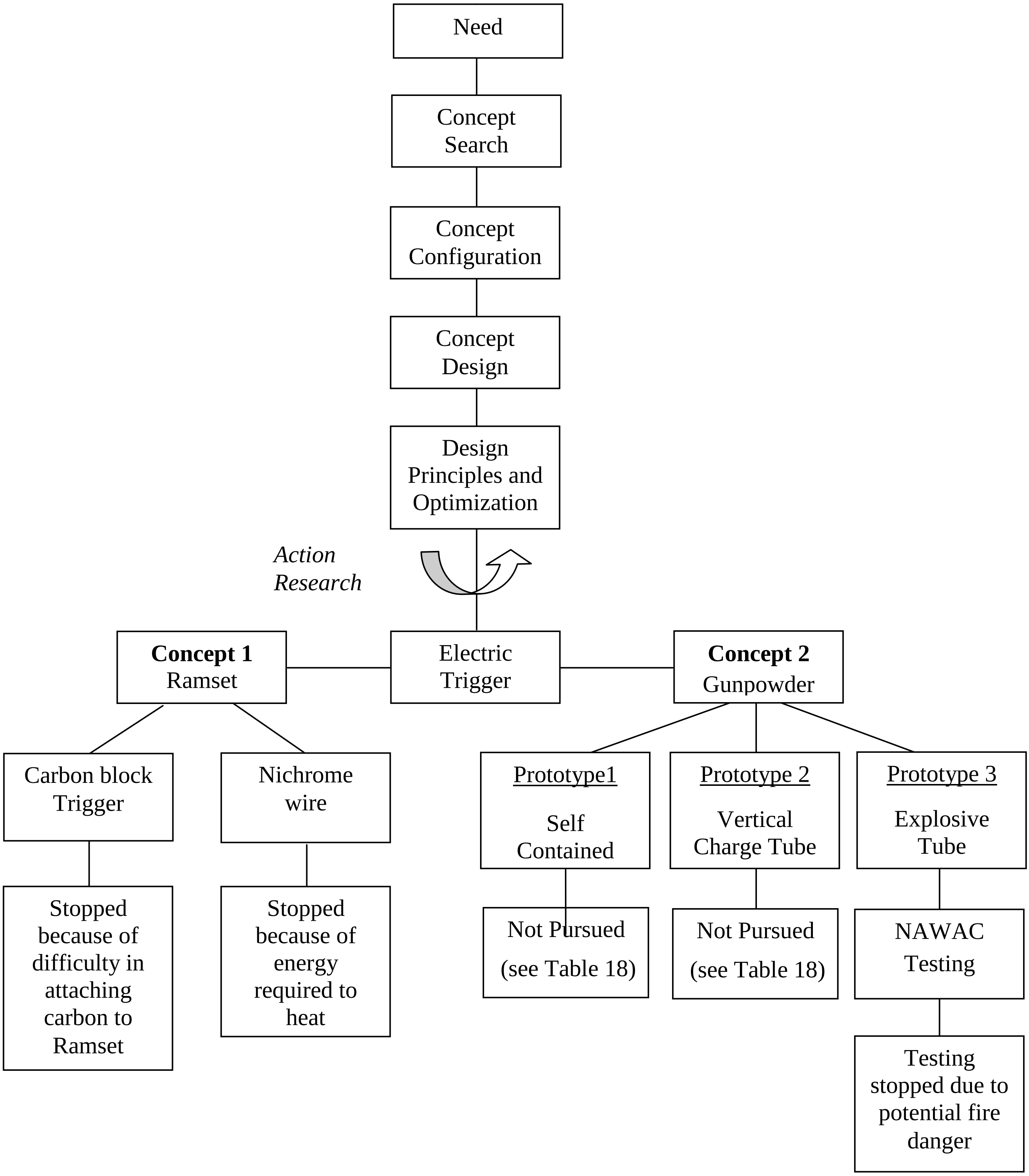


Figure 70 Design flow chart for Electric Hammer

10.9 Design 6: Conclusion

The sparks flying from the trap needed to be addressed before trialing on more ferrets because even if the trap passed the NAWAC guidelines, it would be a potential fire hazard. This potential fire problem was not able to be resolved, and testing stopped due to operator safety issues (mis-firing when turning on) and potential fire hazard in the bush or more open country.

Chapter 11

Concept of a Multi-Species Multi-kill Trap

The objective of this chapter is to develop a concept for a multi-species trap based upon learning through action research and the inventive methodology applied to all the traps developed. The target animals are possums, cats, ferrets, stoats and hedgehogs. Because the strike location for a humane kill varies between animals, it will be difficult for clamping jaws to achieve a humane kill for all species. Because animal diet varies between animals, e.g., cats (carnivore) and possums (omnivore), it is possible that multiple lures or baits may be required.

11.1 Need Analysis

Need Statement*:* *A single trap that can kill possums, cats, ferrets, stoats and hedgehogs.*

11.2 Design Requirements

There was a design requirement that the trap must kill all pest species, and ideally be multi-kill. It should also:

- weigh less than 5 kg
- be capable of killing up to five animals
- be easy to use
- be made of long-life materials
- be cost-equivalent to a possum trap (around $50).

11.3 Concept Search Techniques

An online patent search on the official United States Patent and Trademark Office website (www.uspto.gov) was conducted, along with the Intellectual Property Office of New Zealand (www.iponz.govt.nz/cms). The United States patent search showed up many multi-live capture systems and electrocution-style traps. In the New Zealand patent database there were three automatic electrocution possum traps, NZ 237804, NZ 243144, and NZ 243915. The electrocution style traps, however, would not be suitable for the smaller animals. The electrodes need to contact the head so that the current passed through the heart, otherwise the current would cook the animal alive (D. Hunter, pers. comm., 2004).

The area chosen for further investigation was the use of poison. Poison has the advantage in that there is one poison that will kill all animals, i.e., 1080. The application of poison is generally via a bait station and this has the distinct advantage over traps of being a multi-kill, multi-species system, e.g., rats and possums eating 1080 pellets. Poison is the most cost-effective tool available for pest control (Ogilvie et al., 2000). DOC is not currently carrying out poison operations on stoats, ferrets, hedgehogs and cats (E. Murphy, pers. comm., 2005); but this may change when the PAPP poison becomes available (http://cms.connovation.co.nz/content/documents/Pest-Control-Low-Residue-PAPP-presentation.pdf.). PAPP will not kill ferrets, but does kill all the other species (S. Hix, pers. comm., 2008).

The New Zealand patent search revealed two systems for mechanically delivering poison. The first is patented by Horticultural Research Ltd and involves placing a poison gel on the animal, which the animal will ingest by preening. A concern was expressed by Dr. Elaine Murphy of DOC (E. Murphy, pers. comm., 2004) over taking a poison from a controlled system and leaving potential for uneaten poison to be exposed to species we want to protect. The second patented system for poison delivery, by W. Agnew, is also a gel applicator (NZ 248048) and is commercially available for rats (S. Hix, pers. comm., 2007). A third (not patented) is “Stinger”, made by Stinger Co. (Warkworth, Auckland), a poison injection needle for stabbing possums in the stomach. A possum’s own weight triggers the injection needle as the animal walks on a board to get to the bait. However, there are concerns that needles being bent may cause the system to fail (B. Warburton, pers. comm., 2004).

11.4 Concept Configuration

A mechanical system to deliver a poison was the chosen concept as this has the potential to be a multispecies, multiple-kill trap as animal location may not be as important as other systems, e.g., electrocution or mechanical impact. The chosen poison was 1080, as this can be presented in both powder and liquid form and is known to kill all mammalian pests.

The Animals Australia website describes 1080 as follows:

> “This poison causes a range of symptoms including: anxiety, salivation, nausea, vomiting, incontinence, twitching, auditory hallucinations, organ congestion, renal tube degeneration, respiratory problems, spinal pressure, citrate accumulation in the tissues, convulsions, coma, and eventually death. Animals poisoned with 1080 may take several hours or longer to die” (Animals Australia, 2008).

Animals may also suffer from sub-lethal doses, which I observed during a pen trial on possum. When this happens, they still display many of the visual symptoms listed above. In my opinion, it would be unnecessary to test a mechanical poison delivery device against NAWAC guidelines. In this case it is the dosage of the poison that is doing the killing, and not the application device. The actual dosage required is well documented (Meenken & Booth, 1997).

Poisons have the distinct advantage that animals do not need to be ejected from the killing system, as is the case with mechanical trapping. With direct injection you do not rely on the animal ingesting enough of the poison for it to be lethal, but instead can inject directly the amount of poison required. The no Eggzit trap (Dilks & Laurenece, 2000), which contained whole eggs injected with 1080, was effective only if an animal ingested enough poison. The M-44 (Connolly, 1988) is an example of a spring activated device which blows poison (cyanide compounds e.g., NaCN, KCN, CaCN) into the mouth and face of an animal.

Mechanical systems for delivering poisons also allow for the possibility to automatically refill the poison applicator, creating a multi-kill device and cycling the injection system.

Often it is said that nature is the best engineer of all, and many designers look to nature to seek answers to design issues (Frence, 1988). Nature’s poison dispensers that could be appropriate for adapting for use in a trap, include:

- snakes, via teeth (resembling an injection needle)
- scorpions, mosquitoes, wasps, etc (their stings also resemble injections)
- bees, via a dart/sack system
- cane toads, via poison excretion.

These systems retain and administer the poison; or strike and wait; or allow the poison to be detached and administered. Based on these systems three concepts were considered further.

Concept 1

This concept entails having a bait tube and a poison tube. When it is detected that bait is being consumed, poison would be dispensed into the animal's mouth via the second tube. This is a similar concept to that used by NZ Pat 330900 (Horticultural Research Ltd).

Concept 2

Concept 2 involves injecting a poison into the stomach region of an animal, using a powered needle. A mechanical injection system was patented (NZ 241282) that works via a possum walking on a board, which triggers the release of a static needle that injects the possum in the stomach.

Concept 3

This involves spraying the animal with a poison, which the animal ingests when it preens itself. This system is being investigated by Connovation Ltd. There were three patents covering the application. The first two are NZ Pat 330900 and NZ Pat 248048, owned by New Zealand Institute for Plant and Food Research Ltd, and the third is NZ Pat 230347 owned by Kimber McKenzie.

11.5 Concept Evaluation

All the concepts meet the design requirements (Table 19), but would also need to satisfy ERMA (Environmental Risk Management Authority) and New Zealand Food Safety Authority (J. Ross, pers. comm., 2008) as these poison systems would be a variation on chemical application systems.

Table 19. Concept Evaluation Model for Poison Applicator

Item	**Concept**		
	1	**2**	**3**
Weigh less than 5kg	0	0	D
be capable of killing up to five animals between checks	0	0	A
be easy to use and reliability of kill	-1	-1	T
be made with long-life materials	0	0	U
be similar in cost to a possum trap (about $50).	0	-1	M
Total	**-1**	**-2**	

The datum, concept 3, is the selected concept mainly due to the reliability of kill and the need not to be concerned about precise animal orientation. The design flow chart (Figure 71) is shown below:

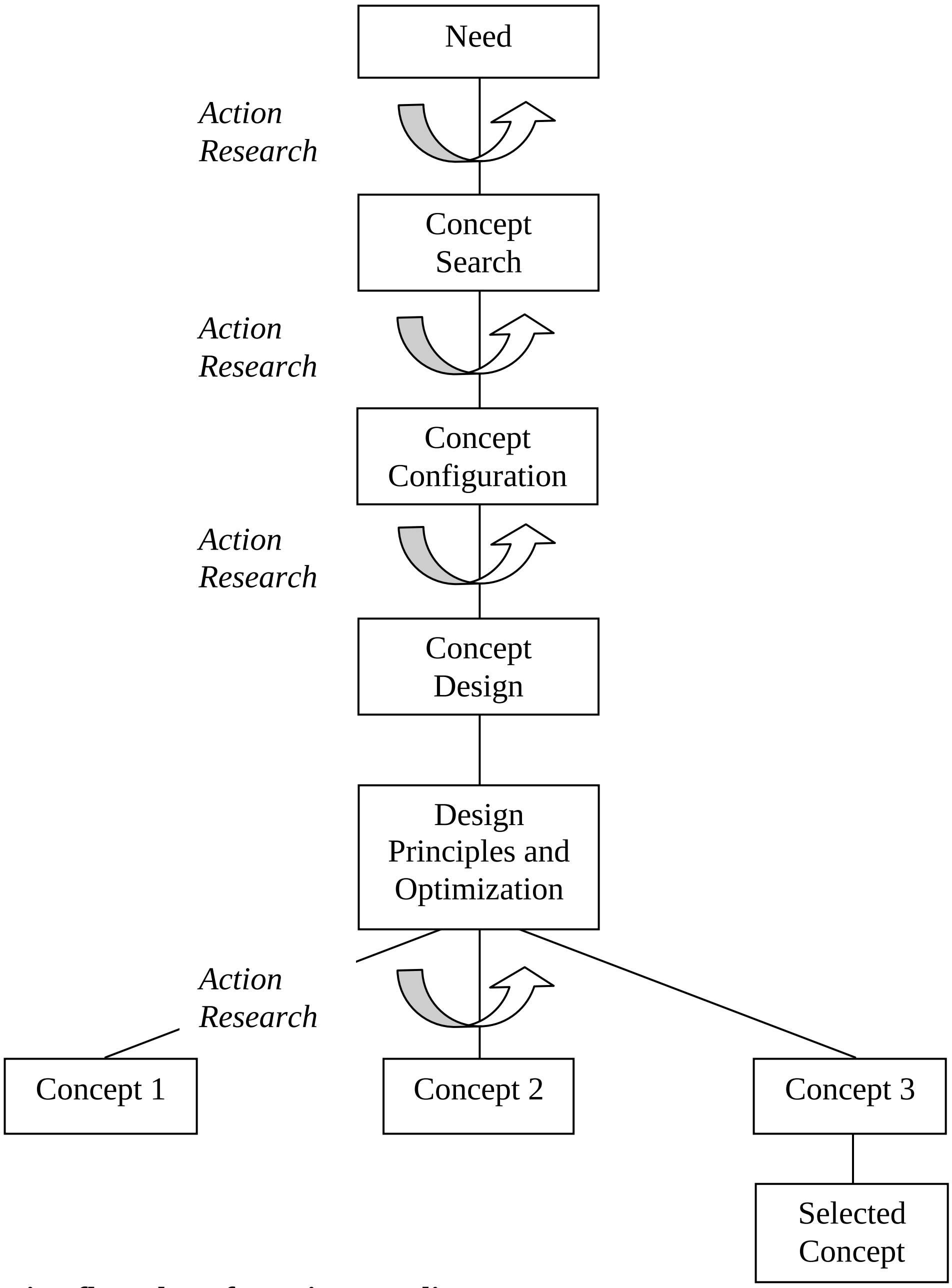


Figure 71. Design flow chart for poison applicator

11.6 Design Conclusions

The integration of a glue and poison will need to be developed and the most likely form of propellant to "spit" the poison onto the animal will be the use of compressed air. The trigger will have to be established after an investigation of natural keys for target animals. The development of concept 3 using the inventive methodology will require much basic research into the ecological/behavioural aspects of the target animals. This future research area is identified in section 15.9.

Chapter 12

Modified Inventive Methodology – Applied to Catching Rats

12.1 Additional Considerations for the Inventive Methodology

The inventive methodology (Figure 72) used so far showed a process which was repeatable and successful in designing animal traps. However, the ecological/behavioural aspects of the animal needed more attention in the concept search technique. This required a better understanding of what an animal does in response to a mechanical situation. Would an animal push on a plate to get to food? What material would they push on the best? How would they push, with their nose, or with their feet? How much would they push? What sort of food should be used? How would different animals react? What degree of trap openness do animals like?

The problem is that most of this basic ecological/behavioural information does not exist for the target animals. In the process of developing the Bulldog trap to the level that it could catch possums (chapter 7), some of the above biodynamic questions were answered; I believe this is partly why the trap was successful. In the following sections I shall introduce proposed changes to the inventive methodology and demonstrate the effect these changes have on the concept design of a rat trap.

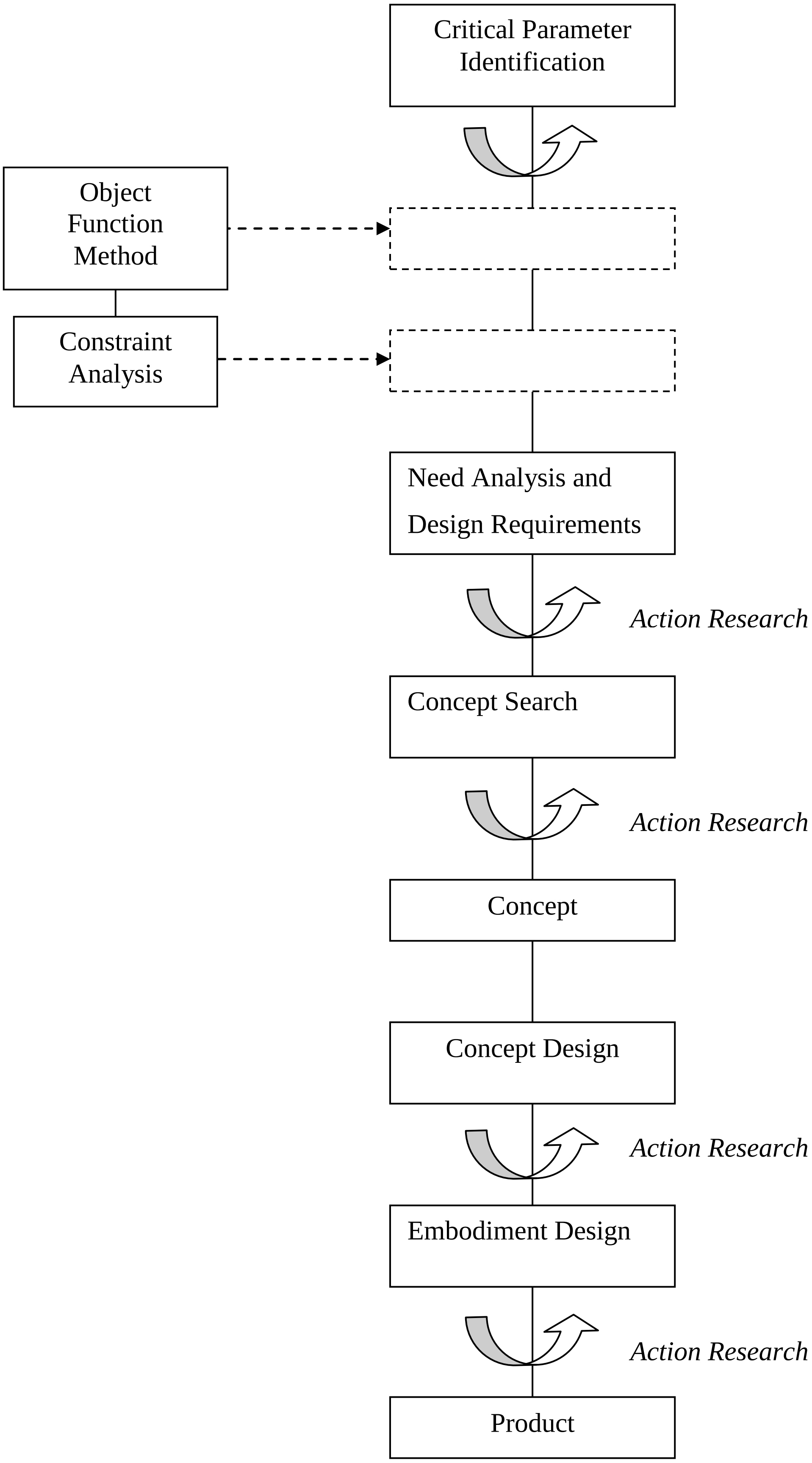


Figure 72. Inventive Methodology

12.2 Finding a "Natural Key"

An addition to the inventive methodology would be to look at what the animals like to do (e.g. beavers like to build dams) in ecologically and behaviourally relevant contexts. These natural instincts could be used against animals in trap design. This "natural key", I believe, needs to be included in the concept search techniques (Figure 73). A patent search and evaluation of existing traps is needed to see if, where and how this approach can be applied in trap designs. The approach of reviewing patents was demonstrated by Altshuller (creator of TRIZ, the Theory of Inventive Problem Solving), who believed that most patents were based on others' work and were simply improvements; and that all design improvements were based on a contradiction, i.e., stronger but lighter (Smith, 2003, p. 2). By reviewing the patents it may yield traps that are using "natural keys" that could be incorporated in the trap design.

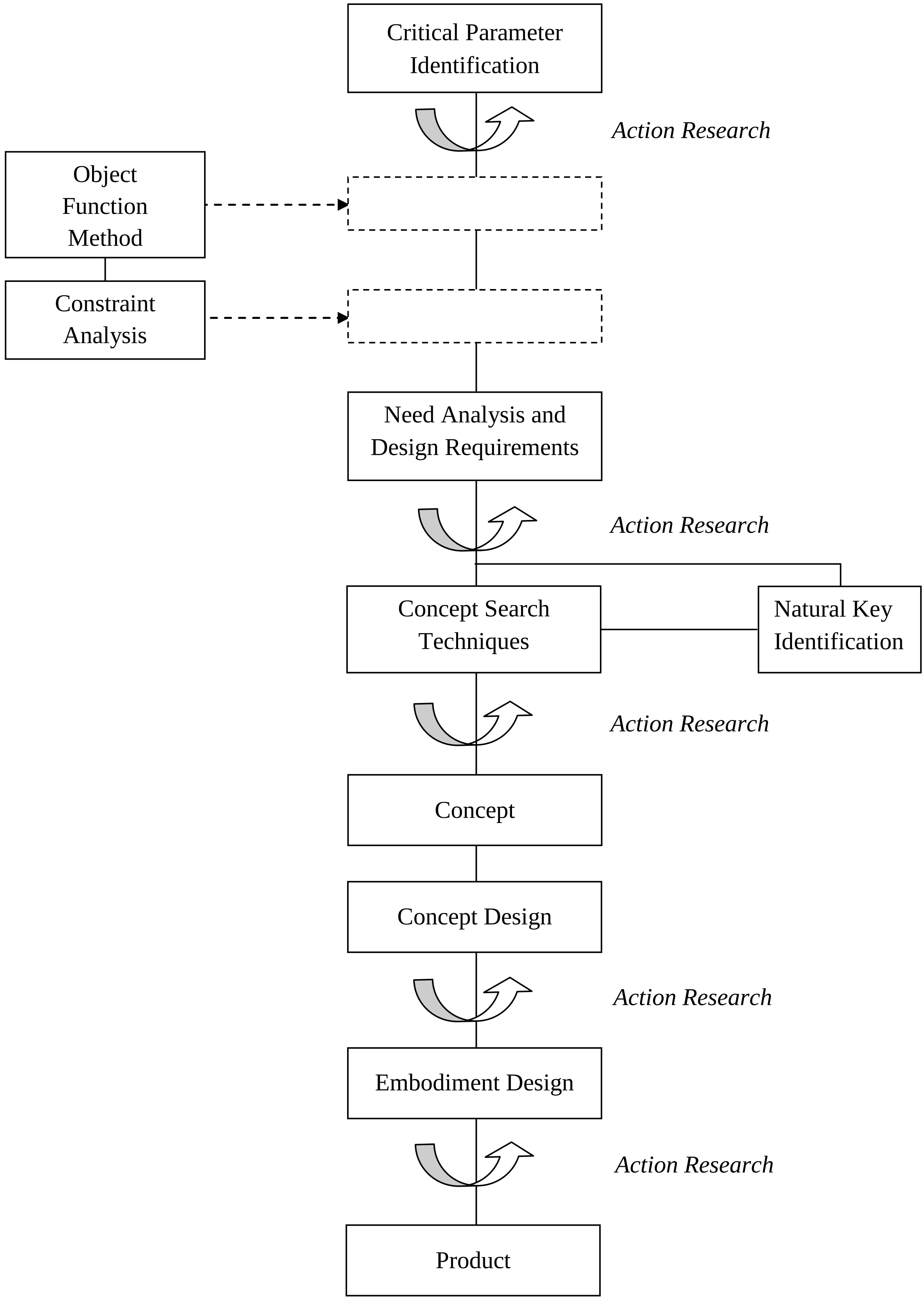


Figure 73. Modified Inventive Methodology

12.3 The design of a Rat Trap

12.3.1 Background

A rat trap will be designed to illustrate this modified process. The rat's most outstanding natural feature is its instinct to steal food (Bennett et al., 2001; Whishaw & Boguslaw, 1996). A patent search of rat traps (www.uspatent.com, February, 2009) registered between 1790-2009 turned up a total of 324 patents, with most traps having the bait attached and when the rat feeds on the bait it triggers the trap. No traps used the bait as the actual trigger mechanism, i.e., using stealing behaviour. However, I am aware of a rat trap developed by DOC St Arnaud that uses the bait as the trigger.

James Henry Atkinson was the British inventor who in 1897 invented the prototype mousetrap called the "Little Nipper". The Little Nipper is the classic snapping mousetrap that we are all familiar with that has the small flat wooden base, the spring trap, and the wire fastenings (Retrieved September, 2007, from www.inventors.about.com/od/mstartinventions/a/mousetrap.htm*)*. Scientists describe the *mousetrap* as a device that is "irreducibly complex." The *mousetrap* cannot be made more simply and still function (Retrieved September, 2007, from www.madehow.com/Volume-5/Mousetrap.html).

Most of the rat trap patents reviewed were based on the Atkinson design, e.g., US Pat 1,330,688 and 1,671,258 are typical examples of this. The problem with the Little Nipper is that when upsized to a rat trap the trap can cause more than a "nip" to your fingers along with not directing the animal, and false triggering. Along with this the trigger requires the spring pressure to set, i.e., you cannot set the trigger without the reaction of the spring on the setting rod, which makes it potentially dangerous when you go to remove your fingers from holding the spring pressure and the trap trigger fails to engage.

12.3.2 Design Requirements

The design requirements address, concerns linked to natural key, design flaws in the existing rat traps, e.g., operator safety. The design requirements are:

- use natural key of bait stealing
- have trigger set without requiring spring reaction (allows for a safety device to be attached)

- have the bait form part of the trigger mechanism
- use the Little Nipper as the base for the design.

12.3.3 Object Function

As this is an existing design, as opposed to all the other traps developed, to form the basis of the design the object function (Chapter 3) is applied (Figure 74).

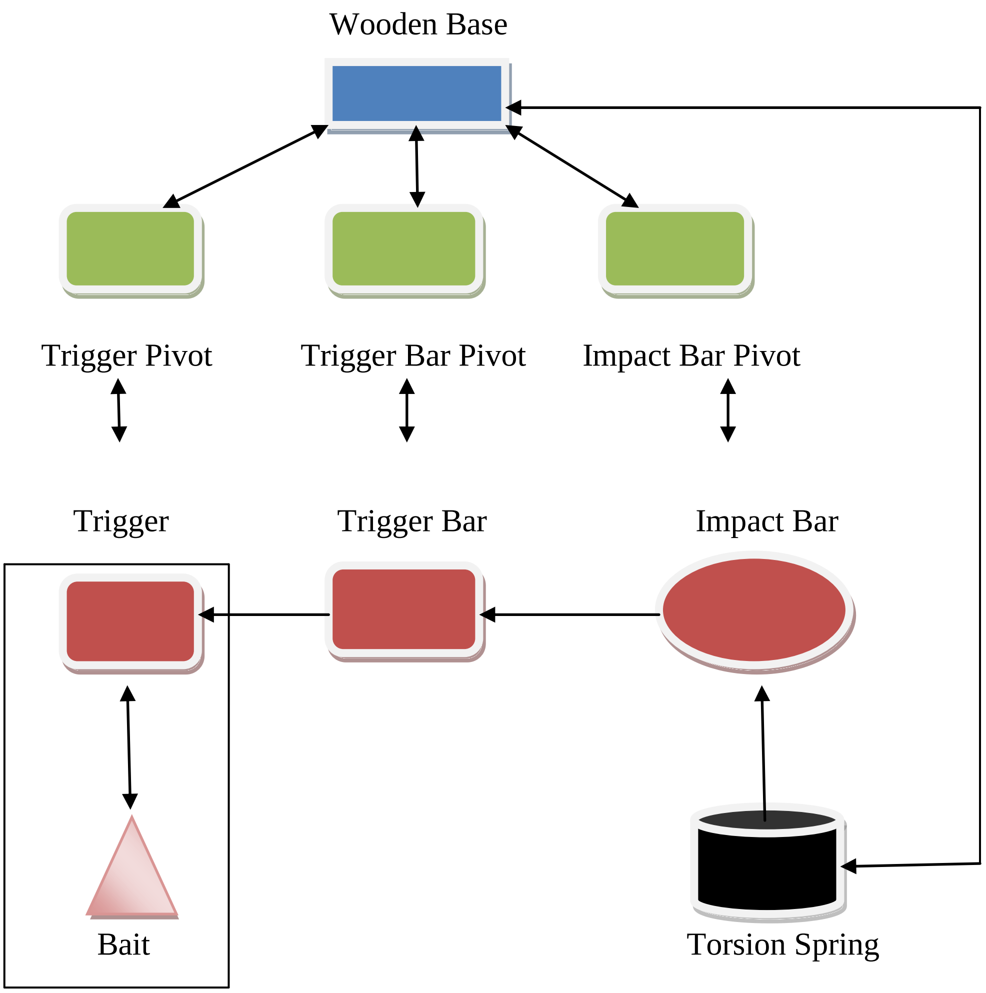


Figure 74. Object Function diagram of Little Nipper mouse trap

The design aim is to incorporate the function of the trigger and bait into one component, being just the bait.

12.3.4 New Design Concept

The bait is to form the trigger along with not requiring the trap spring reaction to hold the trigger in place, which provides for safety to be used so as to ensure the user is not get struck. Along with this the impact bar will be modified as per US Patent 2,592,302 (1950), which will allow for ease of setting by the operator. The proposed concept is shown in the computer generated model (Figure 75). The cover (a) will provide two functions: to orientate the rat, and to limit entry to non-target species. When the bait (b) is disturbed (Figure 76) the impact bar (c) is released.

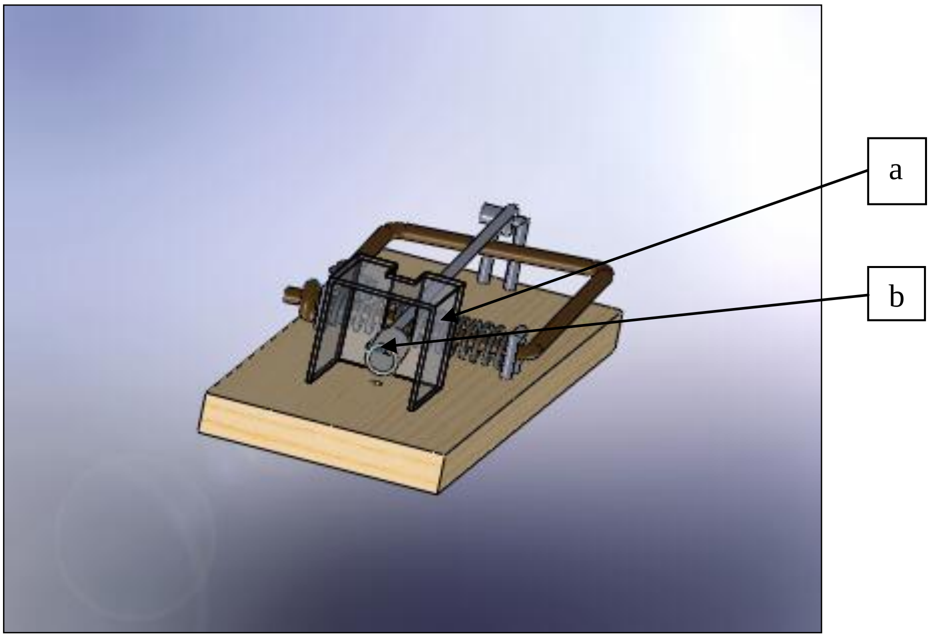


Figure 75. Proposed rat trap in the set position

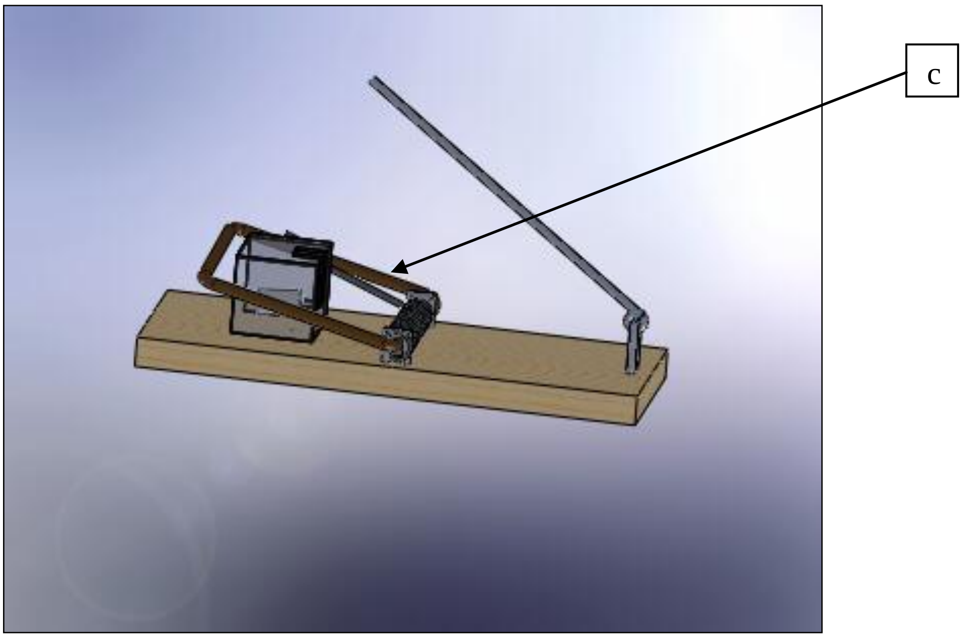


Figure 76. Bait has been disturbed allowing trap to be triggered

12.3.5 Conclusions on Prototype Rat Trap

Integrating the natural key into the design methodology provides a means of creating a trap, which will use the natural behaviour of the animal against itself. The study of the trigger and integrating the natural animal key should provide a means of increasing the catch rate while also meeting multiple design criteria, e.g., improved operator safety.

Chapter 13

Historical Trap Development and the Trap Factor Applied to Trapping Systems

13.1 Development of the Soft-Catch Trap

This thesis provides a sequential design methodology (chapter 3) that can be applied to the design of animal traps. There have been numerous traps developed, e.g., see Bateman (1973) for a summary, and yet there has been no documented methodology apparently used. This section first investigates how trap development and manufacturing evolved for the Soft Catch trap, by reviewing the patent data base to develop the progression of the Victor Soft-Catch® from its earliest documented patent roots (section 13.2). This will demonstrate the incremental improvement from the first concept to the Victor Soft Catch® along with showing the evolution of trap manufacturing companies, e.g., Woodstream Corporation.

Second, section 13.3 compares two entire trapping systems, the leg-hold snare and the padded leg-hold trap, using the Trap Factor (chapter 3). This section concludes by asking: "Can the Trap Factor equation indicate what features a trap designer should concentrate on to improve an existing trapping system?"

13.2 Soft Catch Trap Manufacturing and Development

<u>Manufacturing</u>: Woodstream Corporation

> "Numerous trappers, trap makers, and trap manufacturing companies, small and large, have solved problems of animal capture, profited from their innovations, left their mark on history, and laid groundwork for others to make improvements" (Fall 2002, p. 371).

This interpretation of animal trap development and manufacture is reiterated by Gerstell (1985, p. 296) regarding the manufacture of the "cushion trap":

> "Patented by Charles Bridell US Patent 2,146,464 and manufactured by Charles D. Briddell Inc., which was taken over by the Animal Trap Company of America in 1939

along with Oneida in 1925. By 1940, Animal Trap and Blake & Lamb were the only two major trap manufacturers who combined and formed Woodstream Corporation".

The Animal Trap Company's name was changed to Woodstream Corporation in 1966 and is headquartered in Lititz, Pennsylvania. Woodstream Corporation manufactures and markets pest control, and wildlife caring and control products for the United States, Canada, and European markets. The company offers rodent control products, caring control products for pets and wildlife, pest control products for the lawn and garden, and wild bird feeder segments. It also offers mouse traps, cage traps, toxic insecticides and fungicides, and bird feeders, as well as dog and small animal cages. It distributes its products through retail locations in the United States and internationally (retrieved 25 September, 2010 from hppt://investing.businessweek.com/research/stocks/private/snapshot.asp?privcapId=96531).

Soft Catch development:

The soft catch trap is based on the leg-hold trap and according to Bateman (1973, p 50): "The first evidence comes from Mascall's book, which was published in 1590. Here he describes a variety of traps and the one shown in Figure 77 he describes as: The gripping trappe made of yrne, the lowest barre, and the ring or hoope with two clickets".

It is obvious that it was a double-springed trap of the kind now referred to as a gin or steel trap.

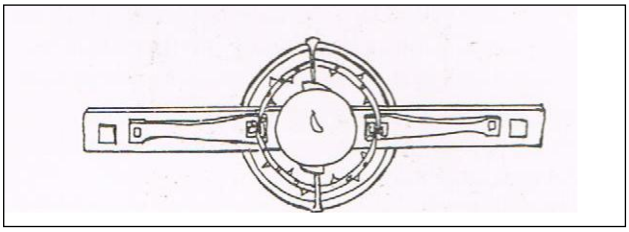


Figure 77. Mascall's iron trap (sixteenth century) (source: Bateman 1973, p. 50)

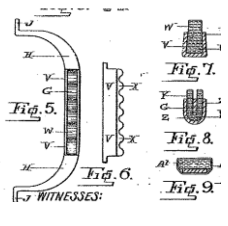
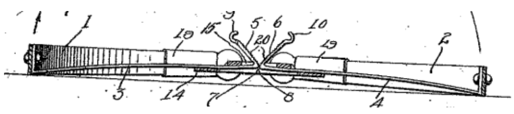
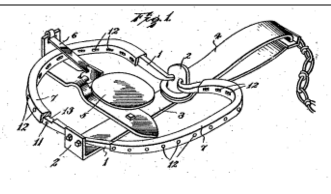
The historical record of improvements is either via patents or historical accounts, e.g., Schorger (1951) and Bateman (1973). The trap patent data base provides a record of trap improvements along with an insight as to why a certain trap is proposed. However, to gain a patent the claim needs to be that: this trap operates in a different or better manner than other traps available. It is difficult to understand the iterations and choices made throughout the design process, as a patent does not usually contain this information, however, it is possible to see the perceived advantages. The first soft-catch was developed (patented) according to the patent claim (US Patent 870,251) to provide a more humane trap by limiting the damage to the animal’s leg. This is a claim that features in all soft-jaw patents (Table 20) and it then becomes an issue as to, what trap, how padding is attached and padding material shape. Although these modifications may seem minor they could result in lowering injury levels (Linhart & Dasch, 1992; Houben et al., 1993; Phillips & Mullis, 1996; Earle et al., 2003) along with excluding non target species (Kamler et al., 2008). The final patents found to limit injury to the animal’s leg used momentum control by slowing down the jaws as they clamp on the animal’s leg, e.g., US patent 4,117,622. Many recent patents are assigned to Woodstream Corporation, e.g., 4,117,622 and 4,175,351, who are ring fencing the soft trap designs, in my opinion.

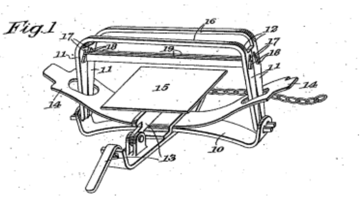
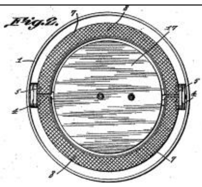
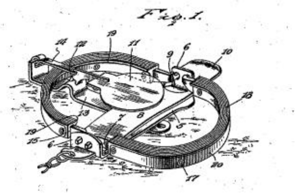
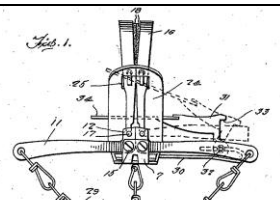
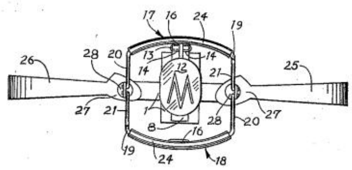
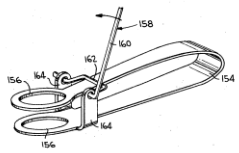
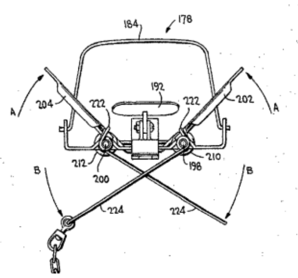
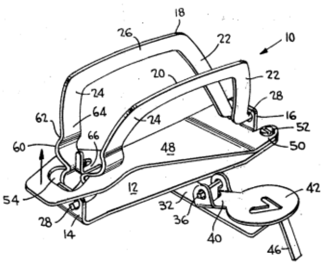
According to Gerstell (1985, p. 268):

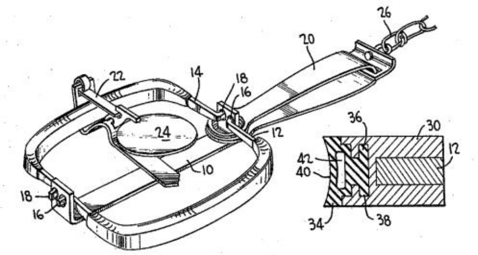
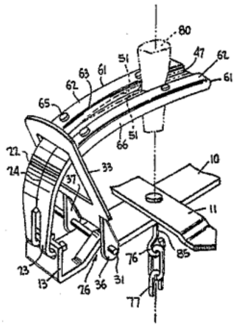
> “The first padded jaw traps commercially were produced in North America, but traps with rubber-covered jaws were made and sold in Europe before 1911”.

I agree with Gersell as the first recorded trap I found, having padded jaws, was in 1906 US Patent 870,251 (Table 20), which would make a trap sales date of 1911 feasible. The main claim of each trap is listed on the right hand column in Table 20. The source for the trap patents was the U.S. patent data base (http://www.uspto.gov/patents/process/search/).

Table 20. Soft Jaw Leg-hold Traps from 1906-1978

Year of patent	Design	Patent Details
1906		US Patent 870,251 The first patented use of “soft jaw” material a humane trap using a pan trigger.
1923		US Patent 1,461,743 A padding rivet to the jaw arms
1929		US Patent 1,825,193 Padding material riveted to jaw

1936		US Patent 2,128,579 A second padded jaw inserted to make it more difficult for an animal to escape
1938		US Patent 1,889,351 A second padded jaw giving the pan extra protection from forest debris
1939		US Patent 2,146,464 Padding material riveted to jaw
1943		US Patent 2,316,970 Padding material riveted to jaw
1976		US Patent 3,939,596 padding material riveted to jaw
1978		US Patent 4,065,871 Momentum control by restricting movement of trap spring.
1978		US Patent 4,117,622 Momentum control by; inertial snubber, escapement mechanism and variable pivot point.
1978		US Patent 4,127,959 Momentum control by: inertial snubber, escapement mechanism and variable pivot point.

1980		US Patent 4,184,282 Padding material cast about jaw
1985		US Patent 4,557,068 Padding material screwed to jaw Victor Soft Catch®

13.3 Using the Trap Factor as an Indicator for Trap Designers

The Trap Factor (chapter 3) is applied to two trapping systems (leg-hold snare and padded leg-hold trap) to investigate if the trap factor can be used as a method to assist trap designers, by identifying areas where a trapping system may be deficient when compared against another trapping system.

Bateman (1973, p. 15) when talking about the snare stated: “Probably no other traps combine so well ease of manufacturing, simplicity of operation and portability”. The snare functions by lassoing the neck, body or paw and tightens to restrain the animal. Snares were often used by poachers and this has contributed to their perceived illegality and humaneness (Bateman, 1973). Leg-hold snares (e.g., US patent 471,911 or 4,171,589) provide a “Soft Catch”, while being less expensive than other traps (McNew et al., 2007). The Trap Factor has demonstrated earlier in this thesis to compare two traps holistically. The Trap Factor may also provide an indication, to a trap designer, the area that an existing trapping system under performs. This concept is now investigated by comparing the leg hold snare to the padded leg-hold trap with the scientific literature providing an indicator for the numerical values of the components of the Trap Factor equation:

Trap Factor = selectivity*humaneness * placement * efficiency * annual cost * ease of use

Some of the Trap Factor values discussed (but not the equation) in the methodology section need to be modified to accommodate the evaluation of the padded leg-hold and leg-hold snare trapping systems. The evaluation of each of the variables is discussed sequentially in section 13.3.1-13.3.6.

13.3.1 Selectivity:

Leg-hold snare:

“Selectivity is usually measured as the number of individuals of the target species caught relative to the number of non-animals” (Issoa et al. 2007, p. 345). The level of selectivity can be of serious concern for conservation if iconic species are caught, e.g., kiwi, golden eagle (*Aquila chrysaeotos*) or bald eagle (*Haliaeetus leucocephalus*) and for this reason a zero value will be given to any trap that captures an iconic species. The difficulty in determining selectivity is that there is variation introduced due to the species being trapped (Table 21). Selectivity can also be influenced by trap type, season, bait and the way in which the trap is set (Dilks et al., 1996; Novak, 1987; Proulx & Barrett, 1993).

Table 21. Selectivity of Leg-hold Snare

Trap Type	Target species	Selectivity	Reference
Leg-hold snare	Lion (*Panthera leo*)	32%	Frank et al., (2003)
Leg-hold snare	Cougar (*Puma concolor*)	45%	Logan et al., (1997)

A high selectivity percentage means a trap is capturing more target species in relation to the total animals captured.

In a Texas study (Guthery & Beasom, 1977) leg-hold snares were determined to be 10 times more selective for coyotes and bobcat than leg-hold traps. Iossa et al. (2007, p. 346) states:

> “Perhaps the greatest advancement to snare welfare would be better training of users....”

Padded leg-hold trap:

Kamler et al. (2008) found that the exclusion efficiency for non target species was 93% when capturing canids, yet Shivik et al. (2005) reported selectivity of 50% and 69% for the catching of coyote (*Canis latrans*).

Trap Factor Selectivity value:

This is difficult to determine as the level of selectivity from the literature can be influenced by trap type, bait or position and by trapper ability. From my own experience I have seen meat suspended above a leg-hold trap at a commercial DOC trapping programme targeting ferrets, the selectivity of such a set is surely questionable. Even with guidelines to avoid non target species, e.g., DOC Best management practices (www.doc.govt.nz), British Association for shooting and Conservation (2002), Defra (2005) and IAFWA (2006) it is possible that non targets will be caught. The literature does not show a large differential between the selectivity of the leg-hold snare and padded leg-hold trap and yet the literature indicates there is scope for improvement. For the above reasons:

Selectivity value = 0.5 is assigned to both trapping systems.

13.3.2 Humaneness:

To determine the humaneness value the literature is used to determine the total trauma caused to an animal caught in a padded leg-hold and a leg-hold snare.

Leg-hold snare:

Bateman (1973, p. 170) states: “Those that are experienced with snares, used either alone or linked with some spring device, consider them to be among the most efficient and humane types of traps for animals”. The use of snares is commonly associated with poachers as historically poachers were able to conceal a snare far easier than a steel trap. The Association of Fish & Wildlife Agencies, (Anon 2009, p. 5) states: “In spite of numerous improvements, laws and regulations in some states still prohibit use of snares, often dating back 50–100 years. Past concerns were frequently based on the belief that snares were highly effective but indiscriminate capture devices that allowed little user control of the capture outcome (e.g., live-restraint versus death). This led to concerns that snares could facilitate overharvest”.

However, McNew et al. (2007) reported a 10% mortality using leg-hold snares when targeting live capture and release. Frank et al. (2003, p. 313) reported that the injuries to African lions were less than using wire mesh cages, and stated:

> "By comparison the wire mesh cage traps typically used for predators in Africa and commonly considered more humane often result in serious damage".

Frank et al. (2003) also noted that some animals struggle more than other animals, e.g., brown hyenas (*Hyaena brunnea*) compared to lions. The location of the leg-hold snare within the forest debris needs to be considered to prevent the trapped animal hanging from its leg.

Roy et al. (2005, p. 1) reported that: "New breakaway devices are being developed and marketed which have different break away strengths ranging from 90-250 lbs (44-120 kg)". These break away systems provides an engineering overload release system that may release larger non target animals, e.g., deer when trapping possums.

Other humane systems have been developed, e.g., relaxing leg-hold snare lock, which allows a snare loop to release constriction pressure on the captured animal when the cable is not taut (e.g., when the animal stops pulling) which means the leg-hold snare fitted with a relaxing lock has a lower static clamp than the padded leg-hold trap.

A review of leg-hold snares was conducted by Iossa et al. (2007) and compared the various trauma scales (e.g., van Ballenberghe, 1984; Tullar, 1984; Olsen et al., 1988; Hubert at al., 1996; Phillips, 1996). The degree of injury was determined by the trauma scale developed by ISO Technical Committee 191 (www.iso.org) in 1999. The ISO Technical Committee 191 scale (appendix D) has four trauma classes (mild, moderate, moderate severe, severe) and the literature prior to this date had two trauma classes these being minor and major. To evaluate the animal trauma using the ISO scale I have modified it to have two trauma classes by combining mild-moderate trauma and moderately severe-severe trauma to align the ISO scale with the literature (Table 22). Therefore, the trauma point rating used is (refer to Appendix D):

major = (moderate severe + severe)/2
= (50 + 100)/2
= 75 points

minor = (mild + moderate)/2
= (10 + 30)/2
= 20 points

Table 22. Summary Review of Leg-hold Snare Trap Injuries

Animal	Number of animals	No injuries	Minor injuries	Major injuries	Reference
Coyote *(Canis latrans)*	23	-	14	9	Shivik et al. (2000)
Coyote	38	2	10	26	Shivik et al. (2000)
Dog (*Canis familiars)*, Red Fox (*Vulpes vulpes)*	117	64	48	5	Fleming et al. (1998)
Canada Lynx *(Lynx canaadesis)*	201	97	92	12	Mowat et al. (1994)
Lion *(Panthera leo)*	27	-	27	-	Frank et al. (2003)
Tiger *(Panthera tigris)*	19	-	17	2	Goodrich et al. (2001)
Raccoon *(Procyon lotor)*	49	40	8	1	Novak (1981)
Cougar *(Puma concolor)*	209	31	174	4	Logan et al. (1999)
Black Bear *(Ursus americanus)*	340	-	330	10	Powell, (2005)
Black Bear	37	26	11	-	Reagan et al. (2002)
Red Fox*)*	117	94	16	7	Englund (1982)
Red Fox	81	56	25	-	Novak (1981)
Total	**1258**	**380**	**772**	**76**	
Average injury per animal		0.302	0.614	0.060	
Trauma per average animal		0	12.3	4.4	Total Trauma per average animal leg-hold snare = 16.7

Padded leg-hold trap

Shivik et al. (2005, p. 1387) states that the: “Padded leg-hold trap showed no indications of poor animal welfare” for the catching of coyote. Other researchers quantified this and by using the same classification system developed for the leg-hold snare it is now applied to the padded leg-hold trap (Table 23).

Table 23. Summary Review of Padded Leg-hold Trap Injuries

Species	Number of animals	No injuries	Minor injuries	Major injuries	Reference
Coyote *(Canis Latrans)*	31	-	26	5	Olsen et al. (1988)
Dog *(Canis familiaris)*	313	-	278	35	Fleming et al. (1988)
Dog	280	-	230	50	Fleming et al. (1988)
North American River Otter *(Lontra Canadensis)*	87	14	50	23	Serfass et al. (1996)
European Otter *(Lutra lutra)*	43	-	37	6	Fernandez-Morran et al. (2002)
Canada Lynx *(Lynx Canadensis)*	39	25	3	11	Kolbe et al. (2003)
Canada Lynx	23	8	6	9	Mowat et al. (1994)
Bobcat *(lynx rufus)*	31	-	24	7	Olsen et al. (1988)
Raccoon *(Procyon lotor)*	100	-	52	48	Olsen et al. (1988)
Gray Fox (*Urocyon cinereoargenteus)*	27	-	18	9	Olsen et al. (1988)
Red Fox *(Vulpes vulpes)*	30	-	28	2	Olsen et al. (1988)
Red fox	19	-	15	4	Meek et al. (1995)
Red fox	28	10	6	12	Englund (1982)
Red fox	91	48	39	4	Travaini et al. (1996)
Total	**1142**	**105**	**812**	**225**	
Average injury per animal		0.09	0.71	0.20	
Trauma per average animal			14.2	15.0	Total Trauma = 29.2

Trap Factor Humaneness value:

The humaneness value for leg-hold traps is not as definitive as for kill traps, most likely due to the ease that death is able to be measured. The humaneness value for the Trap Factor is a ratio of the humaneness value based on the trauma scale developed by ISO Technical Committee 191 (Appendix D). "These trauma scales assess injury, they do not incorporate variables such as pain", according to Iossa et al. (2007, p. 343). While broken teeth receive a relatively low trauma score, orofacial pain is some of the most intense pain on pain scales for humans (Tandon et al., 2003).

Using the total trauma values from Table 22 and Table 23 to determine the humaneness rating:

Padded leg-hold =

$$1 - \frac{\text{Trauma padded leg hold}}{\text{Trauma padded leg} - \text{hold} + \text{Trauma Leg} - \text{hold snare}}$$

= 1 – (29.2/(29.2+16.7))
= **0.36**

Leg-hold snare =

$$1 - \frac{\text{Trauma padded leg hold}}{\text{Trauma padded leg} - \text{hold} + \text{Trauma Leg} - \text{hold snare}}$$

= 1 – (16.7/(29.2+16.7))
= **0.64**

Humaneness values: **Padded leg-hold = 0.36**

Leg-hold snare = 0.64

13.3.3 Placement:

Trap placement is based on the volume or weight of the trap as detailed in chapter 3 (maximum weight of 20 kg and a pack volume of 75 l). Table 24 tabulates the weight of the padded leg-hold and leg-hold snare for various animals.

Table 24. Number of Traps that Can be Carried for Target Animals.

Animal	Padded leg-hold trap (weight kg, volume l)	Leg-hold snare (weight kg, volume l)
Bear	20 kg 20 l (www.bugspray.com) Max number by weight = **1** Max number by volume = 3	1 kg (3/16 cable) + tube 25 l (www.pscoutdoors.com) Max number by weight = 20 Max number by volume = **3**
Coyote, dog, fox	0.450 kg 0.6 l (www.trapping.com.au) Max number by weight = **44** Max number by volume = 125	0.200 kg (3/32 cable) 0.08 l (www.pscoutdoors.com) Max number by weight = **100** Max number by volume = 938
mink, muskrat, possum, racoon	0.380 kg 0.5 l (www.pestcontrolresearch.co.nz) Max number by weight = **52** Max number by volume = 150	0.120 kg (1/16 cable) 0.08 l (www.pscoutdoors.com) Max number by weight = **167** Max number by volume = 938

Average maximum number padded leg-hold = (1 + 44 + 52)/3 = **32**

Average number snare leg-hold = (3 + 100 + 167)/3 = **90**

Placement leg-hold Snare = Average number snare leg-hold/(Average number snare leg-hold + Average number snare leg-hold)

= 90/(90 +32) = 0.74

Padded Leg-hold = 0.26

Placement values: **Padded leg-hold = 0.26**

Leg-hold snare = 0.74

13.3.4 Efficiency:

The problem in evaluation of trap efficiency, according to Munoz-Igualada et al. (2010, p. 185) is: “how a device is set also influences efficiency”. In my experience I would also include trapper acceptance of the trap, trapper bias, and the animals being captured. The capture efficiency according to Fleming et al. (1998, p. 330):

“is inherently biased, being affected by the experience of the trapper, the population density of the target and non-target animas previous exposure of the targeted population to trapping, the sex and age structure of the targeted population, and seasonal site characteristics”.

Leg-hold snare

Fleming et al. (1998, p. 335) found:

> “The treadle snare missed more target animals than it caught. Most trappers would find this rate of capture unacceptably low.”

Regan et al. (2002, p. 319) found a difference in the triggering mechanism of the leg-hold snare, i.e., “Trapping efficiency, measured by trap-nights/bear was greater for passively triggered snares than spring activated snares.”

Padded leg-hold

Warburton (1998b) reports in excess of 30% possum escapes out of Victor Soft Catch® traps and believed that further research is required to understand the reasons for the high escape rate in padded as opposed to unpadded jaws. Others have also experienced a lower efficiency of padded as opposed to unpadded equivalents (Tullar, 1984; Linhart et al., 1986). However, Linhart & Dash (1986, p. 63) reported that for capturing coyote:

> “The Soft-Catch trap was re-engineered to increase closure speeds became available in 1988. Field testing of this model, which incorporated specific trap setting procedures, showed increased performance which equalled unpadded models”.

This increase in capture rate was also reported by Skinner & Todd (1990) through later modifications to padded traps by an increase of closure speed.

Trap Factor efficiency:

The literature has not demonstrated a clear relationship between the catch rate of leg-hold snares and padded leg-holds, and for this reason a sensitivity analysis is performed. The evaluation of the efficiency is by a comparative ratio of the target catch rates (chapter 3). Therefore, there is a proportional relationship between the two variables (Table 25).

Table 25. Relationship Between the Efficiency of Leg-hold Snare and Padded Leg-hold

Efficiency leg-hold snare	Efficiency padded leg-hold
0.1	0.9
0.2	0.8
0.3	0.7
0.4	0.6
0.5	0.5
0.6	0.4
0.7	0.3
0.8	0.2
0.9	0.1

13.3.5 Annual Cost:

There are many different types and sizes of leg-hold snare traps so that as the size of the animal increases so does the cost of the trap. The proportional cost of a leg-hold snare will be less than that of the padded leg-hold because the ease of manufacture and materials cost will be less for the leg-hold snare (Table 26). The leg-hold snare cost appears to be of the order of 7-9 times cheaper than the padded leg-hold.

Table 26. Cost of Leg-hold Snare and Padded Leg-hold Traps

Animal	Leg-hold snare	Leg-hold
Bear	$56NZ M15 foot snare www.snareshop.com	$375NZ #16 Bear Trap www.bugspray.com
Canine	$15NZ www.snareshop.com	$65NZ KB5 www.trapping.com.au
Possum	$7NZ www.snareshop.com	$65NZ Victor Soft Catch® www.trapping.com.au

Leg-hold snare

The leg-hold snare varies in cost from $7-$56NZ (www.snareshop.com) dependent upon the animal being targeted and whether the leg-hold snare was powered and assumed to have a ten year life. The average cost = (56 + 15 + 7)/3 = $26

Annual cost = cost/trap life= $26/10 years = $2.60/year

Padded leg-hold

The padded leg-hold average cost = (375 + 65 + 65)/3= $168

Annual cost = cost/trap life = $168/10 years = $16.80/year

Trap Factor Annual cost value:

Leg-hold snare = 1-(2.60/(2.60 + 16.80)) = **0.86**
Padded leg-hold = 1-(16.80/(2.60 + 16.80)) = **0.14**

13.3.6 Ease of use:

Leg-hold snare:

The leg-hold snare requires a degree of experience greater than setting a steel leg hold trap, however, there are powered leg-hold snares that use a spring power source to set the leg-hold snare, e.g., Aldrich trap (Poelker & Hartwell, 1973) which requires less bushcraft to set. However, the literature (e.g., Iossa et al., 2007, Fleming et al., 1998) is clear that there is a higher skill level required to set a leg-hold snare as opposed to a leg-hold trap. The ease of use value is a subjective value and based on the above literature I have assigned a value of 0.2 to the ease of use.
Ease of use leg-hold snare value = **0.2**

Padded leg-hold: e.g., Victor Soft Catch®
The Victor Soft Catch® requires skill to ensure that pan trigger levels are correct which would be part of any normal maintenance programme. Otherwise, it is an easy trap to set.
Ease of use factor Victor Soft Catch = **0.9**

13.4 Trap Factor Evaluation

In Table 27 the Trap Factor value is calculated without the inclusion of the efficiency, as the literature was not definitive, consequently a sensitivity analysis was performed (Table 28). The sensitivity analysis showed that the leg-hold Trap Factor was only higher for the first case (efficiency snare = 0.1).

Table 27. Trap Factor for Leg-hold Snare and Padded Leg-hold Trap

Trap	Selectivity	Humaneness	Placement	Efficiency	Annual cost	Ease of use	**Trap Factor**
Leg-hold snare	0.50	0.64	0.74	X	0.86	0.2	**.0407**
Padded leg-hold trap	0.50	0.36	0.26	X	0.14	0.9	**.0006**

Table 28. Sensitivity Analysis for Trap Factor (Efficiency)

Efficiency Snare	Efficiency Leg-hold	Snare Trap factor	Leg-hold Trap Factor
0.1	0.9	0.0041	0.0053
0.2	0.8	0.0081	0.0047
0.3	0.7	0.0122	0.0041
0.4	0.6	0.0163	0.0035
0.5	0.5	0.0204	0.0029
0.6	0.4	0.0244	0.0024
0.7	0.3	0.0285	0.0018
0.8	0.2	0.0326	0.0012
0.9	0.1	0.0367	0.0006

13.5 Conclusions

The Trap Factor equation compared two different trapping systems (i.e., snare and leg-hold traps) and clearly shows that the snare traps have a higher Trap Factor even given a small efficiency as shown by the sensitivity analysis (Table 28). The snare system performed well in humaneness, placement and annual cost compared to the padded leg-hold. The snare's high performance in the humaneness was a result I did not expect, possible due to my preconceived ideas on snare humaneness and my inexperience with snare use. However, to balance this, according to Iossa et al. (2007, p. 344) “Trap-based injuries are rarely reported in scientific papers and, as such, makes it hard both to improve and to compare trapping techniques”. There have been large improvements in snares, overload release systems, swivels, shock springs, self releasing systems, coated wire and cable design described in the literature. Munoz-Igualada et al. (2010, p. 186) state:

> “Our results support previous assertions that well-designed, stopped cable restraints can be a useful method to catch foxes without severe injury”.

This is also reiterated by Fleming et al. (1998, p. 337):

> “Restraint (snare) setting procedures can impact efficiency and welfare: however, so as to ensure best practices additional research may need to be complemented with adequate regulations and training programmes for trappers”.

The initial question was:

> “Can the Trap Factor equation indicate what features a trap designer should concentrate on to improve an existing trapping system?”

For trap designers the Trap Factor has shown that the snare system needs more research conducted on selectivity and an understanding of “natural keys” (chapter 12) would assist the designer. The ease of use needs to be integrated with the selectivity while maintaining the high ratings in the other Trap Factor values.

Chapter 14

Animal Traps and Animal Welfare Issues

Overview

A potential problem arises when new traps have been classified under NAWAC. Specifically, what is the certainty that they will perform to this standard after being set in the bush for a number of years. This could result in people believing that they are killing in a humane manner when they are not. In this chapter I explore two key mechanisms potentially prone to loss of performance. First, in section 14.1 I discuss the springs used in kill traps and introduce some of the inherent problems with springs. Second, in section 14.2 I investigate the actual loss of strength of DOC 200 traps.

14.1 Trap Operation

Spring-powered animal traps normally use torsion, tension or compression springs (Figure 78) as the means of powering the trap jaws. All trap springs are subject to a loss of strength (Warburton et al., 2002) if they are continuously loaded (hysteresis); however, torsion springs also have the problem of deformation occurring in the torsion arm (Figure 79). When the torsion arm deforms this does not allow for the spring coils to deliver their energy to the trap jaws. The impact load is well in excess of 1000 g (I. Domigan, unpub. data), which ripples it's way through the spring arm. I found that traps that initially have a very high clamping force can dramatically reduce their strength, with some losing up to 30% after their first time operated (see Warburton & Poutu, 2003).

Given the environment that the traps operate within, often the coils will rust together (Figure 79). The fusing of the active coils induces higher stress into the connection arms when the trap is set, due to there being fewer coils to absorb the twisting effect when the trap is loaded and consequently deforms. This loss of strength due to fusing of coils can also happen in compression springs (if left in choke position) and tension springs (if coils are touching under static loading). For a tension spring the rusting of coils causes other coils to become overloaded, as they need to expand more. The common traps used in New Zealand (Table 29) are classified according to spring type used, with a distinction made between an integral torsion spring and a torsion spring. In an integral torsion spring the spring is also the moveable jaws that hit the animal from both sides.

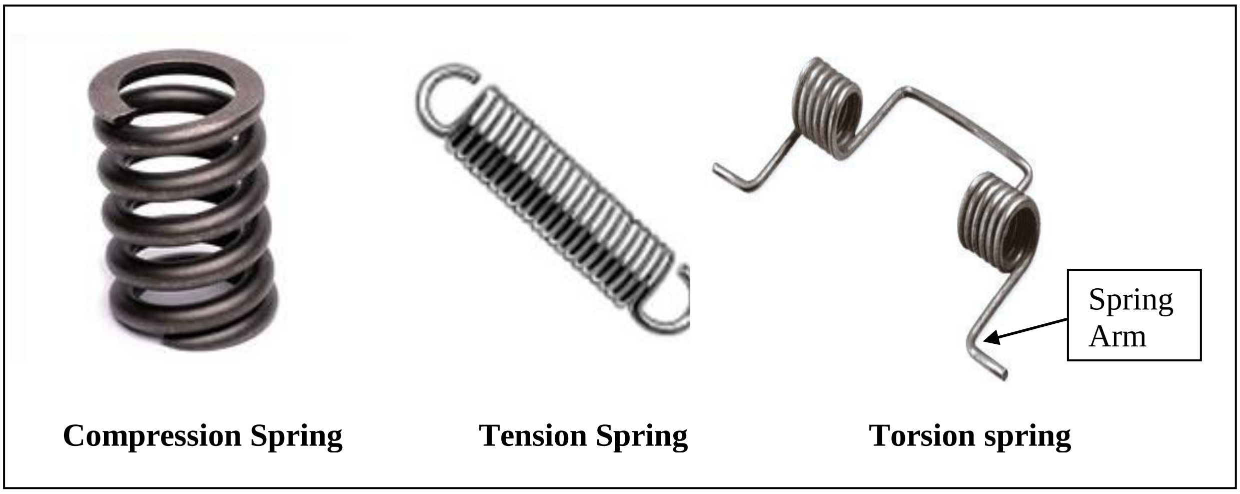


Figure 78. Compression Tension and Torsion springs

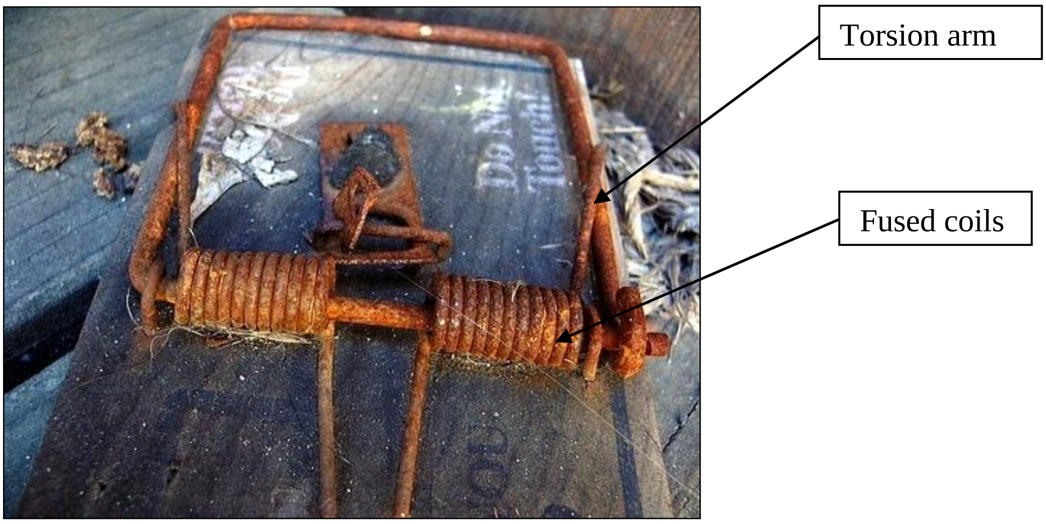


Figure 79. Torsion spring active coils rusting together

Table 29. Spring System used in most Commonly used Traps in New Zealand

Torsion spring	**Integral torsion Spring**	**Tension spring**
Victor rat trap*	LDL 101*	Timms**
Fenn**	Set and Forget*	Blitz**
DOC Series*	Warrior/Bulldog*	Dominus*
Holden**	Conibear*	Kakai
Donaldson**		Thumper*
Most leg-hold traps		

* Achieved NAWAC’s Class A or B standards for species tested.

** Failed to achieve NAWAC’s Class A or B standards for animal tested.

14.2 Field Trial

The fact that torsion spring traps lose their effectiveness over time has major implications for animal welfare concerns. A trap may satisfy the terms of NAWAC's guidelines in the testing phase, and yet become inhumane in the field. Seventy four DOC 200s were tested for mean clamping strength after a period of 18, then again at 33 months to determine the loss of strength (Figure 80). The trap load was measured at 10mm trap opening. The traps were located along Takaka's Howard's Hole track. To fully ascertain as to when a once humane trap becomes inhumane needs more research. However, this result has raised a concern for animal welfare regarding the need for a spring renewal system to be considered.

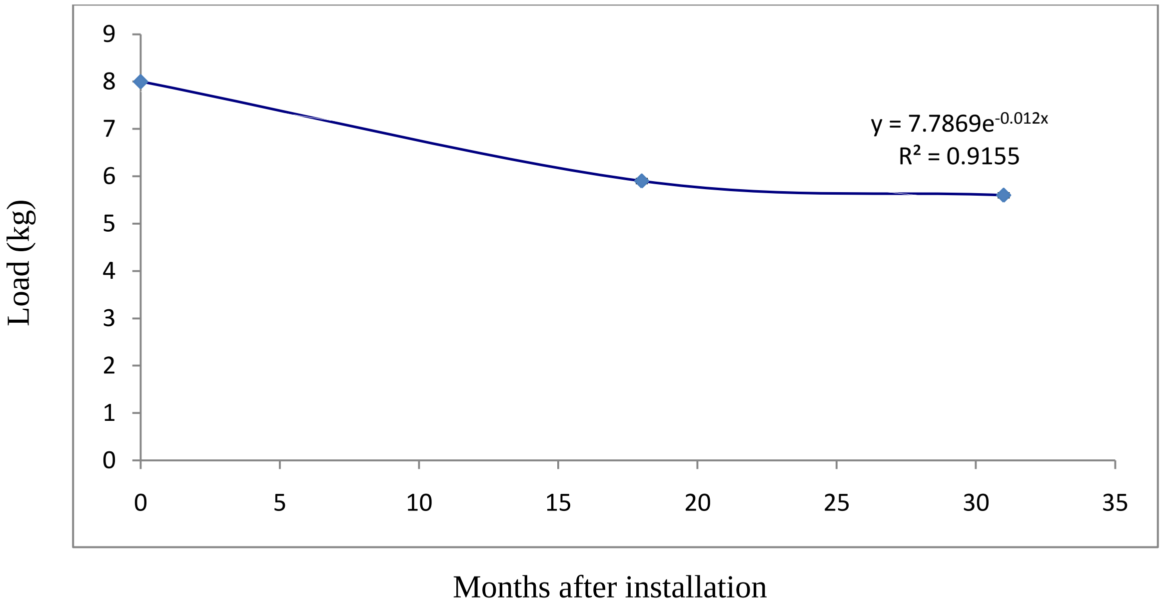


Figure 80. Loss in spring strength of DOC 200 traps (n =74)

The error bars for the load measurement were all 0.004 kg and consequently do not appear on Figure 80.

14.3 Conclusions

This field trial of DOC 200 traps demonstrates how a once humane spring trap loses strength over time. To determine when these traps will become inhumane will need further research, which is beyond the scope of this thesis. The equation of the line in Figure 80 is highly dependent upon the starting clamp (8 kg) for a new trap. As the initial clamp was taken from the manufacturer's specification (www.predatortraps.com) it would be sensible to repeat this experiment to reaffirm the measurements.

Chapter 15

Conclusions

This chapter demonstrates how the aim of the thesis was achieved via the research objectives and discusses the new knowledge achieved. The research objectives are presented sequentially with areas of future research identified at the end of the chapter.

- Section 15.1 looks at the literature review to establish a design methodology: **objective I.**
- Section 15.2 looks at the inventive methodology identified for the invention of animal traps: **objective II.**
- Section 15.3 looks at the results of my application of inventive methodology applied to the invention of animal traps: **objective III.**
- Section 15.4 looks at the methodology for the comparative evaluation of animal traps: **objective IV.**
- Section 15.5 looks at modifications made to the inventive methodology: **objective V.**
- Section 15.6 looks at the limitations of the research.
- Section 15.7 questions whether the **thesis aim** been achieved.
- Section 15.8 details the awards and patents achieved during this thesis research.
- Section 15.9 concludes with areas that may need further research.

15.1 Conclusions on Literature Review

The review of the literature indicated the need for the thesis aim and gave examples of how others had attempted and failed to achieve the aim of developing an inventive methodology for traps. The literature review identified and discussed the social and humane standards along with a historical perspective on how traps have been developed in the past and explained why there was a need for change now. This review also showed how societal concerns influence change due to technological advances, e.g., bio-control techniques can cause societal views to change in relation to animal control. In many engineering innovations society is often the commentator in the form of art and literature, e.g., Watt (steam engine), Turner (painting) and Dickens (literature). But for animal welfare, societal response varies according to the wealth of the country, and the literature demonstrated this in that there is no one standard for humaneness. The literature review thus created the framework, under which animal trap innovation can occur. The literature review also indicated that there was the possibility of using cues from animals that may increase their catch rate, e.g., Dilks (1996) showed how the use of wooden boards increased the catch rate of rats. There was however, little indication of what needs to be addressed in basic trap design to increase the catch rate.

The animals to be targeted were introduced in the literature along with the reasoning for why stoat, ferret and possum were singled out for the design of traps. There is little doubt that without intervention to control these introduced species many more native fauna and flora would become extinct on the New Zealand mainland.

The literature review therefore reinforced the need for a holistic approach to the evaluation of animal traps as there was no such approach found in the literature.

15.2 Inventive Methodology

The integration of inventive methodology with Action Research and Cooperative Inquiry led to a modified participatory inventive methodology where the inventor stills remains central, but better informed. Action Research (Plan-Act-Observe-Reflect) was a dynamic process changing in form, swinging between Participatory Action Research (PAR) (where the participants are strongly involved with many phases of the research) to that of Cooperative Inquiry (where participant input is highly controlled). The boundaries between PAR and Cooperative Inquiry are fluid with participant flow being “checked” by the inventor who is central in the inventive methodology. For example, there were times when it was advantageous to encourage PAR, e.g., having marketing people involved in the field work and manufacture, and essentially getting participants to ‘buy into’ the process, thereby creating a degree of ownership with the final product. The important step for me was to exclude participation at the concept development phase otherwise I risked the problem of something being designed by a committee and constraining the invention along with no inventor to take ownership. The Cooperative Inquiry input was at the stages of parameter identification, need analysis, concept search technique, conceptual design and embodiment design allowing the inventor to progress unobstructed through the object function model and concept development phase. The Cooperative Inquiry, for me, was via talking to trappers, ecologists, biologists, manufacturers and via meetings with environmental groups and DOC staff. The single ownership, I believe, is important as it will usually require a blind determination to achieve the goal of invention. Others see this as:

"*Invention is 2% inspiration and 98% perspiration*." (Thomas Elva Edison www.wilywalnut.com/edison.html, accessed June 2009)

It was not until I went to the Brainwaves (2009) seminar on how the brain works that I realised that for the act of invention to occur the person must be in a heightened state of relaxation. This is why we have those "aaahhh" moments, e.g., ideas gained while walking on the beach or being in a shower. The relaxed mind state is essential to the act of invention and this methodology would fail if a person is not in the right mind space when developing concepts. This is also well recognised by the greatest inventor of our times:

"The brain can be developed just the same as the muscles can be developed, if one will only take the pains to train the mind to think." (Thomas Elva Edison www.wilywalnut.com/edison.html, accessed June 2009)

Related to the above, I was encouraged by the degree of influence the concept filter had on the concepts and the selection of a high grade filter developed very good traps, e.g., using the Timms trap operation as the filter forced the invention of the Thumper, Dominus and Blitz traps. The matrix evaluation system ensured that the prototype with the highest potential for success progressed to the prototype phase. I could also return to this point and carry on the design with the second highest ranked prototype if required (Figure 81). I did not use the object function and constraint analysis in the development of a new invention; however, the object function method assisted in understanding the relationship between the components and helped to optimise the design. The object function method was demonstrated in the development of the new rat trap (Chapter 12).

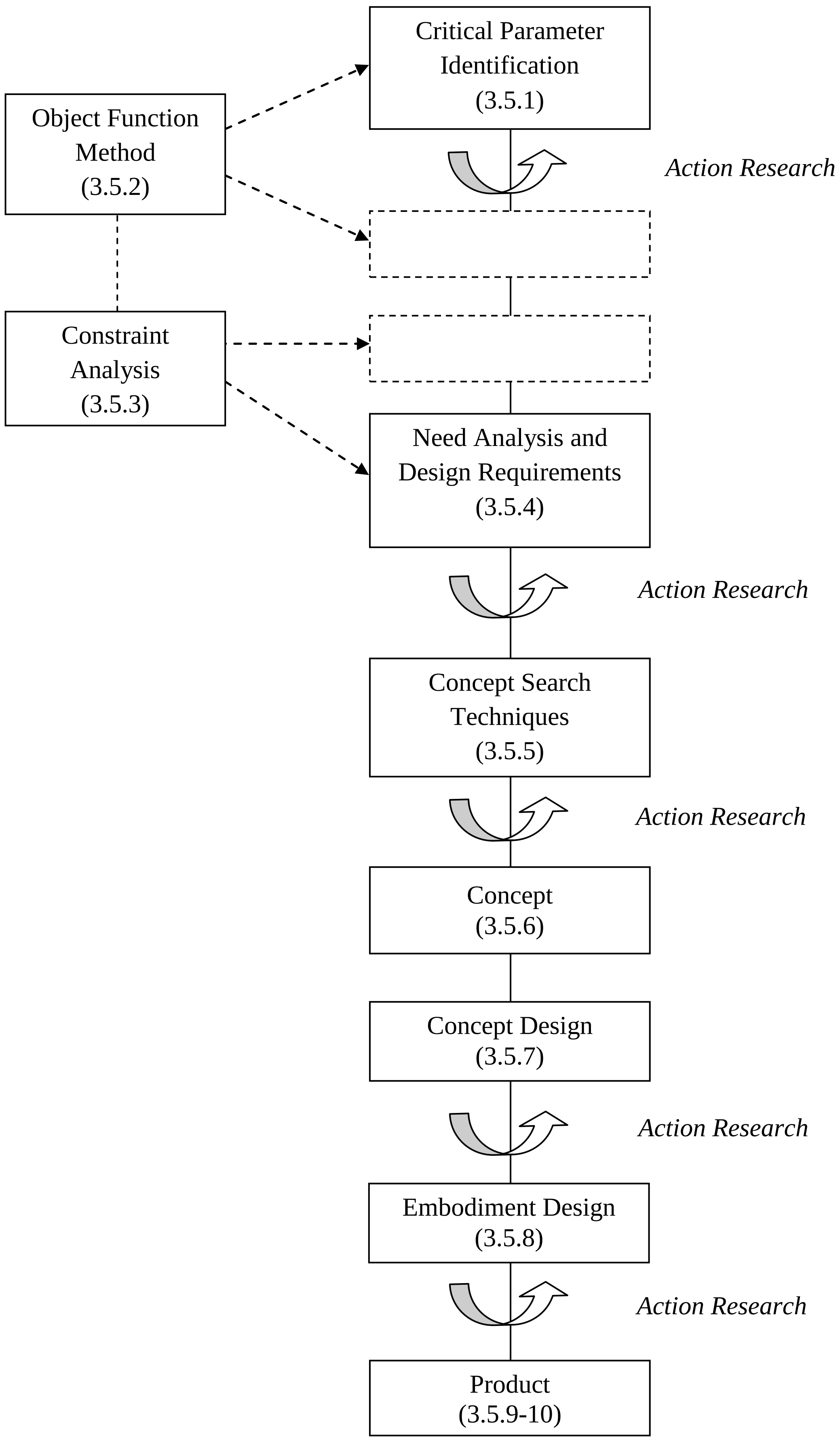


Figure 81. Schematic representation of the Inventive Methodology (Numbers in brackets refer reader to relevant section)

The inventive methodology allows for innovation by improving an existing product by entering the inventive methodology via the existing product design routes as shown in Figure 81 which also integrates the input from the Action Research cycle (shown as the circular arrows in Figure 81.) The input areas from others is shown as Action Research bearing in mind that the input varied from Cooperative Inquiry to PAR during the cycle.

The object function model (section 3.4.) was responsible for raising questions about why there was a spring and a body for the Bulldog trap (section 7.6) and resulted in these two functions being incorporated into one. This is an example of the product improvement methodology path as shown in Figure 81 taking the path from product to object function model.

Chapters 4-11 demonstrate the repeatability of the inventive methodology with Chapter 12 identifying a further improvement through the incorporation of natural keys in trap design. A methodology I developed for the comparison of traps is now reviewed.

15.3 Methodology for the Comparison of Traps

The methodology, called the Trap Factor, provided a means of comparing traps based on more than simply the attribute of catch rate. The trap factor was easily applied taking a very broad brush approach ensuring that it did not get caught up in detail. The comparison allowed for an inhumane trap (as defined by NAWAC) to still have the ability to have a higher rating than a trap that passed the NAWAC humane standards class A or B. The example of this was shown in section 6.2 when the Thumper was compared against the Fenn, with the Fenn having the higher rating even though it had failed the NAWAC testing protocol. The Trap Factor equation also demonstrated, the obvious result, of a trap that had passed NAWAC and had a higher catch rate to achieve a Trap Factor higher rating, e.g., Dominus compared to Fenn (section 6.4).

It is important to consider the Trap Factor equation criteria. There is a degree of subjectivity when it comes to measuring ease of use, whereas humaneness, trap placement, annual cost and efficacy are all quantifiable.

From a logic viewpoint the use of large traps that are disproportional to the animal size being targeted makes little sense and the Trap Factor methodology has thus proven its ability to holistically quantify the performance of an animal trap. Another benefit of the Trap Factor methodology is that its non complex application means that it can easily be applied to existing data sets. The Trap Factor also demonstrated its ability to identify areas a trap designer should focus on (chapter 13).

15.4 Traps that Result from Application of NAWAC Guidelines

In this section I compare and contrast the traps I developed against other traps that have passed the NAWAC guidelines and look at the key trap design species; stoat, ferret and possum. My research confirmed what Warburton et al. (2002) demonstrated, i.e., that the force required to kill an animal is not necessarily proportional to its size. The hierarchy based on the force required to humanely kill is, from most to least: ferret, possum, cat, stoat, hedgehog and rat. Because traps are based on entry requirements, a ferret trap will usually exclude possums and cats while allowing entry to stoat, hedgehog and rat. Thus, in terms of force, the killing of the ferret becomes the key requirement for trap design. Likewise in terms of strength possums are stronger than cats so they become the key trap design species. The reason for a stoat being a key species is that ferrets are not found in the inner bush (King, 2008). The catching of rabbits in traps tends to be a by-catch as control is usually by poison. The catching of mongoose and brown tree snake, while conducted in Hawaii, are important to simply demonstrate the versatility of the traps developed in terms of catching of other pest species worldwide.

Lesson Learnt: *The size of the animal does not necessarily relate to the killing force required to kill the animal humanely.*

An overview of the traps developed, name, technology used, animals targeted and whether the trap satisfied Class A or B of the NAWAC guidelines is shown in Table 30, followed by an overview discussion of stoat, ferret and possum.

Table 30. Traps Developed Showing Target Animal and Technology Used

	Over Centered Loaded Spring		Positively Loaded Spring		Explosive	
Animal	Thumper	Blitz	Bulldog	Dominus	Hammer	Electric Hammer
Rat	Passed NAWAC			Passed NAWAC	Passed NAWAC	Expected to catch but not tested yet
Hedgehog		Has Caught	Has Caught	Has Caught		Expected to catch but not tested yet
Stoat	Passed NAWAC	Has Caught		Passed NAWAC	Passed NAWAC	Expected to catch but not tested yet
Ferret		Failed NAWAC	Failed NAWAC	Has Caught	Passed NAWAC	Failed NAWAC
Possum		Has Caught	Passed NAWAC			
Cat		Has Caught				
Rabbit				Has Caught		
Mongoose*				Has Caught		
Brown tree snake*				Has Caught		

Key:

- Passed NAWAC
- Failed NAWAC
- Has Caught
- Expected to catch but not tested yet
- * Traps tested overseas

15.4.1. Stoat Traps developed as a Result of NAWAC

The DOC 150-200 range requires a box and is 20 times heavier and 10 times bulkier than using Fenn traps in Philproof covers that were previously used by DOC. The DOC design has thus led to a bulkier trap than previously existed. The cost of placement needs to be factored into the Trap Factor equation (chapter 3) to give a true indication of the value of a specific trap when being compared against an alternative system. There has been no consideration to the loss of strength over time of the DOC traps (chapter 14), as to when they will become inhumane and need replacing, as is the case with all spring powered traps in New Zealand. The question that needs answering for all traps is; “Once a trap has passed the NAWAC Class A or B standard how quickly will the trap become inhumane?”

Lesson Learnt: *Spring powered traps once passed the NAWAC criteria will at some time become inhumane.*

Lesson Learnt: *The Trap Factor equation needs to be applied when comparing traps, as opposed to simply considering catch rate only.*

The gaining of acceptance of new traps for DOC, I believe, is going to be difficult due to the in-house style of development. Not only are the same individuals that are involved with the development also advising on the style of trap to be used, they are also involved with the writing of Best Management Practices (BMP) and involved with field trials. This has the potential to compromise these individuals. This was recently demonstrated by direct funding from the manufacturer to these same DOC staff (The Press, p. 3, Mongoose predator control in Hawaii, 26 April, 2009) to promote their product. It seems likely that without independent peer review and/or use of the Trap Factor equation, similar sorts of issues to those described above will occur in the Hawaiian work.

A three year comparative study between the DOC 200 and Fenn traps was reported by Kirk (2008) to have cost $56,000. The BMP for the use of the Fenns was not used. The BMP for the use of Fenn Mk 6 for killing stoats recommends that a double set configuration is used (i.e. two Fenn traps per tunnel). The most likely reason why this BMP was not followed for the Fenns is that the DOC 200 traps when put together in a box set each other off. This therefore biases the trial in favour of the DOC 200 because as Christie et al. (2003) showed, two Fenns caught at higher rates when paired (BMP for Fenns). There are already indications that a mono trapping system (i.e. the use of a single brand of trap) may not give adequate protection, i.e., the need to remove animals in Okarito (www.terranature.org/kiwiRecoveryIssues, accessed May 2007) and in Fiordland (The Press, 8 August 2008, "Stoats kill kiwi chick in protected region"), even after an intensive trapping programme. To potentially overcome the problem of trap-shy animals the possibility of providing alternative styles of traps rather than a single trap needs to be investigated, however this is beyond the scope of this thesis. There needs to be extensive field trials conducted between the DOC 200 and the Dominus trap (Appendix A) to determine the catch rate and then the Trap Factor equation applied to each trap.

Lesson Learnt: *(i) In-house trap development by government agencies has the potential to stifle trap innovation. (ii) In-house trap development by DOC has the potential to bias findings against externally developed traps.*

The Thumper trap used a push trigger. This was initially chosen to ensure that the traps were not filled up with rats, and would be available to catch stoats. From my observation of rat behaviour, it was noted that rats were unwilling to push against a steel trigger. The push trigger excluded rats successfully as the trials in Wanaka (Barry Laurence), Whangarei (Lyoyd Williams) and my Flea Bay trial demonstrated. However, it also reduced the catch rate of stoats. When the trigger system of Thumper was changed to a treadle (Appendix A) the catch rate of stoats and rats instantly increased.

Lesson Learnt: *A treadle trigger will have a higher catch rate than a push trigger, but is non selective.*

The Hammer trap also had the issue of a push trigger system and as shown in the Flea Bay trial the push trigger catch rate was significantly lower than that of the treadle trigger. The Hammer trap needs to be redesigned to incorporate a treadle trigger as the amount of power the trap can exert on the animal is limited by the power of the charge selected, independent of the trigger sensitivity, which is a great advantage over mechanical systems.

To create a small stoat trap the head region explicitly needs to be targeted (Warburton et al., 2002) as was also demonstrated by the Thumper and the Hammer traps. If the head region is not targeted then larger traps are required, i.e., DOC series, to deliver the lethal blow across the entire head and body region. The problem with applying higher impacts is that it causes the skin to rupture and results in increased bleeding which is highly corrosive and will ultimately cause increased rusting of the trap. This is confirmed by the DOC traps needing the treadle to be made of stainless steel as opposed to mild steel as the rusting of the treadle plates was excessive (I. Domigan, pers. obs., 2008).

Lesson Learnt: *To create a small stoat trap the head region needs to be targeted. Larger strike zones result in larger traps which cause the animal to bleed onto the trap. The blood increases the rusting of the trap, thus requiring more expensive materials.*

Lesson Learnt: *There is a need for cleaning and maintenance of traps.*

15.4.2 Ferret Traps Developed as a Result of NAWAC

The Hammer and the DOC 250 are the only traps that can kill ferrets within the NAWAC guidelines. The trials with the Blitz trap (section 9.10) showed that targeting the ferret's neck region to occlude the carotid artery or wind pipe required a load in excess of 30 kg on a 0.91 mm bottom bar.

Lesson Learnt: *To humanely kill a ferret by targeting the neck region will be beyond the strength of spring powered traps.*

The electric hammer (chapter 10) showed that the ferret became wary when taking a bait on a bait bar and would quickly retreat outside the trap (section 10.7.1) once encountering the bait.

Lesson Learnt: *Ferrets become wary when they actually come to take the bait as opposed to travelling to reach the bait. This wariness on bait approach was also observed with rats, possums and stoats.*

The ferret proved a formidable opponent and targeting the skull seems the most sensible area for the design of future traps. However, they did not appear to be trap-shy in pen trials but given that these animals had been previously caught in traps we were possibly dealing with non trap-shy animals.

The force delivered by the Hammer trap was independent from the trigger force as a higher powered charge could be used. This is an attribute which no other spring powered trap can match and makes the design unique.

Lesson Learnt: *Ramset® power tool blanks provide a means to deliver high force to the ferret's head to kill it.*

Given that the Hammer is not commercially available and the DOC 250 costs in excess of $170 for a double set, there exists an opportunity for a developer to target ferrets with a new trap design. The AHB is prepared to fund the testing of such traps (J. Ross, pers. comm., 2008).

Lesson Learnt: *There is a need for a cheaper ferret trap that obtains a Class A or B classification under NAWAC.*

15.4.3 Possum Traps Developed as a Result of NAWAC

The Bulldog trap was a complete success. The commercialisation of this trap means it commands 35% of the kill trap market (S. Hix, pers. comm., 2008). The Bulldog trap showed how a trap that failed initially could be turned into a success by changing the jaw positions relative to each other (section 7.6) and by employment of a trigger (section 7.7). This work has shown that the Bulldog trap needed:

- a pull trigger as opposed to a push trigger
- the top jaw overlapping the bottom jaw
- openness on the sides

- a clamp of 20 kg (10mm opening) on 1.6 mm jaw thickness.

Lesson learnt: *Some attributes of existing traps can be used as a basis for new trap design.*

The implementation from researcher to commercial manufacture also showed the problems of passing over a design to a company who had little understanding of the reasoning behind the choices made in the design.

Lesson learnt: *Designers need to be actively involved in the manufacturing decision to ensure strategic functions of the design are not lost.*

There is little scope for more possum traps given the compact size (200mm x 50mm x 150 mm), weight (0.8-1.0 kg) and retail cost ($35-40) for the Warrior (Bulldog)/Set and Forget Trap (Appendix B) and Timms (section 8.1.5) ($70-85) due to the cost of development and NAWAC testing.

15.5 Modified Inventive Methodology

Through the development of my inventive methodology being a blend of Action Research, Co-operative inquiry and linked to a product design cycle (Chapter 3) I have developed a repeatable design process that can be used by future trap developers. Criteria for trap evaluation were developed by Temme & Jackson (1979), however, these "criteria" were looking at how rats react to traps as opposed to a system that could be implemented during design.

My work indicates that the methodology needs to be developed further by adding a step to incorporate "natural keys" of the target animal that make them prone to trapping. Thus, I disagree with Newcombe (1981) who suggested that the kinetic energy and clamping force be the primary design criteria based on threshold values determined by experimentation. The secondary characteristics are location of impact, triggering, size and weight, safety, ease of setting, reliability, maintainability, flexibility and performance. The approach of Newcombe (1981), in my opinion, is a purist approach that would be used in designing a structural element but has little application in the designing of a successful animal trap as there is no consideration of the animal in the design. This is a mistake that I initially also made. This was the reason why the "Thumper trap" failed to achieve a high catch rate, due to my not understanding the importance of studying animal behaviour in relation to the trigger system.

Cook et al. (1973, p. 35**)** stated "...that the task of killing or rendering an animal unconscious instantly, or reducing the time required to do so, cannot be resolved properly unless the animal's behaviour in approaching the trap and reacting to the trigger is studied at the same time". I agree with this statement as when the trigger system was changed to a treadle (Dominus) higher catch rates were instantly obtained (Appendix A). The "natural keys" need to be well identified for the target animal(s) and the trigger system designed to take these natural keys into account. These natural keys will come from observing how animals react to triggering and baiting systems. From my observations some natural keys for specific animals are:

- Rat: stealing of bait, rears up on hind legs prior to entry,
- Stoat: will dig when unable to get to bait.

It was only toward the end of my research that I realised the importance of these "natural keys" in the design of traps and these natural keys are based on observations with no hard quantifiable data to back up the statements above. There is a need for more research to be conducted in this area, perhaps collaboratively between designers and ecologists with the latter responsible for gathering such data.

My research has added to the basic data that trap designers require, however there is still a need for impact clamp curves to be developed for stoats and ferrets as was done for possums (Warburton & Hall, 1995b). From these impact clamp curves it may be possible to determine when a trap will start to fail. There will however be the need to consider impact stress when developing these curves. There is still little basic research available to the trap designer mainly due to the fact that most of the trapped species in New Zealand are actually protected in other countries. If the basic research is not done the reaction of trap manufacturers is to over design so they will pass the animal humaneness guidelines. This was the case in Canada where manufacturers simply made the traps more powerful (B. Warburton, pers. comm., 2004) as a way of passing the animal welfare issues. My development of Hammer using explosive charges does however allow for more powerful traps to be constructed without an increase in triggering force and trap weight. The success or failure of a redesigned Hammer trap will be subject to a "natural key" being identified and the modified inventive methodology then applied.

15.6 Limitations

The time and cost of performing the field trials (Kirk & Gillies, 2008) to obtain statistically valid results was limited by the abundance of predators and the number of traps required.
The field trials of the Thumper trap (380 traps) went to too large a scale trial before smaller mid size trials were conducted. This was partially due to the funding needing to be used within a five year period. A related issue was my naive belief that once a trap performed well in a pen trial it would be replicated in the field. The remote locations throughout New Zealand made the monitoring of the trials very difficult along with key staff at DOC offices changing.

15.7 Achievement of Thesis Aim

The aim of this thesis was to: Identify and modify a design methodology suitable for the invention of animal kill traps and develop a methodology for the comparison of traps, all consistent with the intentions of the AWA.

The thesis aim to develop a methodology for the invention and evaluation of animal traps has been comprehensively proven by undertaking designs progressively using more advanced forms of the inventive methodology. The use of co-operative inquiry and Participatory Action Research in the inventive methodology provides an opportunity for the inventor to fully understand the design issues and, yet rightly, excludes these participants from the concept generation phase. The "natural keys" provide an opportunity to exploit the animal's natural instinct in such a way as to increase catch rates. This is going to require experts from ecology and biology to identify these "natural keys" so they can be incorporated into the inventive methodology prior to the concept generation phase.

The traps I developed have demonstrated that the New Zealand humane standards are achievable and Class A status should be possible for all animal traps in the future with the use of Ramset® blank charges as a technique to achieve Class A status for multiple species. The holly grail in trap design is to provide an automatic trap for the cost of a single kill trap and I believe this is possible by the use of the inventive methodology.

The proof of any methodology is answered if others can follow through the same process and achieve similar results. To demonstrate that my inventive methodology could be used by others I used a second year diploma class I teach at Lincoln University as a trial case study.

The students had the inventive methodology explained to them with me leading them through each step. To ensure that the students were relaxed I always moved the class (this was never explained to them) from where we were meeting to a location that required a five minute walk and had told them to start to think of concepts to solve the issues that had been identified just prior to moving. This was using skills that I had learnt in the Brainwaves (2009) seminar as previously mentioned. The end result was that the student's inventions won the Invention of the Year Award 2009 and Young Inventor of the year Award 2010 at the National Agricultural Fieldays. "New Zealand National Agricultural Fieldays is the largest agribusiness exhibition in the Southern Hemisphere. New Zealand is a world leader in agriculture and pastoral farming and the National Fieldays is the ultimate launch platform for cutting edge agricultural technology and innovation" (www.fieldays.co.nz, accessed 6 December 2011).

This demonstrated beyond question that the inventive methodology could successfully be used by others.

The Trap Factor equation developed has shown to provide logical solutions and an ability to be easily applied to existing data sets and this new knowledge will provide researchers with a holistic approach to trap evaluation as opposed to a monolithic approach.

15.8 Awards and Patents

During the course of this research the new knowledge was recognised in the issuing of two provisional patents, two full New Zealand patents and one international patent. The innovation of using a Ramset® charge in the Hammer trap won the gold award for innovation at the National Fieldays held at Mystery Creek (2005) along with the design of the Thumper/ Dominus trap winning the new product section gold award. In 2006 the best demonstrator award for the demonstration on how trapping systems operate was won.

15.9 Further Research

The following are areas which require further research:

- The identification of "natural keys" for rats, stoats, ferrets and possums that will make these animals more prone to being trapped.

- A comparison between the Dominus trap and the DOC 200 using the Trap factor equation to determine the “overall” best trap.
- A redesign of the Hammer trap trigger that will ultimately increase the catch rate.
- The development of automatic poison delivery systems.
- The development of an electrically powered blank with minor trigger delay.
- A better understanding of the timing of trapping operations in relation to the species being protected.
- The need for a high powered conventional (e.g., Victor) rat trap using natural keys to target stoats.
- The need to establish the relationship between trap size and target animal weight to help guide trap inventors.
- An investigation of the catch rates of a mono trapping, e.g., Fenns system, compared to a multiple trap, e.g., Fenns and DOC 200 system.

References

Alber, R., & Rudolph, S. (2002). On a grammar-based design language that supports automated design generation and creativity. In J.C. Borg & K.P. Farrugia (Eds.) *IFIP WG5.2 Workshop on Knowledge Intensive CAD (KIC-5),* St Julians, 23-25 July 2002 (pp. 80-89) Malta. Retrieved September, 2006, from http://www.isd.uni-stuttgart.de/~rudolph/engdesigne/design_publications.html.

Aldwell, F. E., Keen, D. l., Parlane, N. A., Skinner, M. A., de Lisle, G. W., & Buddle, B. M. (2004).Oral vaccination with *Mycobacterium bovis* BCG in a lipid formulation induces resistance to pulmonary tuberculosis in brushtail possums. *Vaccine*, 22, 70–76.

Ali, A., & Falkenburg, D. R. (1999). A Framework for design process specifications. *Journal of Engineering Design*, 10(3), 223-245.

Allen, W., Bosch, O., Kilvington, M., Oliver, J., & Gilbert, M. (2001). Benefits of collaborative learning for environmental management: Applying the Integrated Systems for Knowledge Management approach to support animal pest control. *Environmental Management*, 27(2), 215-223.

Alterio, N. (1996). Secondary poisoning of Stoats (*Mustela erminea),* feral ferrets (*Mustela furo),* and feral house cats (*Felis catus)* by the anticoagulant poison, brodifacoum. *New Zealand Journal of Zoology*, 23, 331-338.

Alterio, N. (2000). Controlling small mammal predators using sodium monofluoroacetate (1080) in bait stations along forestry roads in a New Zealand beech forest. *New Zealand Journal of Zoology*, 24, 3-9.

Alterio, N. (2006). Spring home range, special organisation and activity of stoats *Mustela* erminea in a South Island *Northofagus* forest, New Zealand. *Ecograph*y, 21(1), 18-24.

Anderson, L. (2003). Hot topics in the United States regulatory environment. In L. Carson (Ed.), *Proceedings Australian and New Zealand Council for the Care of Animals in Research and Teaching (ANZCCART), Christchurch, 18-19 August 2003* (pp. 61-63). Christchurch, New Zealand.

Animals Australia (2008). *Introduced Wild Animals Fact Sheet*. Retrieved September 24, 2008, from www.animalsaustralia.org/documents/.../IntroducedWildAnimalsFactSheet.pdf.

Anonymous. (1999a). *Animal Welfare Act 1999*. New Zealand Government Press, Wellington, New Zealand.

Anonymous. (1999b). *Guide to the Animal Welfare Act 1999. Ministry of Forestry Policy Information paper No 27*. Ministry of Agriculture and Forestry, New Zealands Government Press, Wellington, New Zealand.

Anonymous. (2000). *NAWAC 2000 Draft guidelines. Mammalian restraining and killing traps*. *National Animal Welfare Advisory Committee*. Ministry of Agriculture and Forestry, New Zealand Government Press, Wellington, New Zealand.

Anonymous. (2001). *Bovine Tuberculosis National Pest Management Strategy 2001-2013.* Animal Health Board, Wellington, New Zealand.

Anonymous. (2004). CEDAR. Doing Action Research Key learning and emerging principles. Community Economic Development Action Research Project, *CEDAR Thematic series 02/04*. Retrieved September, 2008, from http://www.dol.govt.nz.

Anonymous. (2006). *Best Management Practice for Trapping in the United States*. Association of Fish and Wildlife Agencies. Washington, United States of America. Retrieved October, 2007, from www.fishwildlife.org.

Anonymous. (2007a). *Best Management Practices for trapping Opossums in the United States*. Association of Fish and Wildlife Agencies. Washington, United States of America. Retrieved November, 2008, from www.fishwildlife.org.

Anonymous. (2007b). *Certified Traps - AIHTS Implementation*. Fur Institute of Canada Retrieved November, 2008, from www.fur.ca.

Anonymous. (2009). *Modern Snares for Capturing Mammals: Definitions, Mechanical Attributes and Use Considerations*. Association of Fish and Wildlife Agencies. Washington, United States of America. Retrieved September, 2010, from www.fishwildlife.org.

Austin, J., Chamberlain, M. J., Leopold, B. D., & Wes Burger, L. (2004). An evaluation of EGG and wire cage traps for capturing raccoons. *Wildlife Society Bulletin*, 32(2), 351-356.

Ashley, S. (1990). Rapid Prototyping systems. *Mechanical Engineering*, 112(11), 34-39.

Barlow, M. (1995). Habitats and factors affecting breeding success at eleven *Caspian Tern Sterna caspia* colonies in New Zealand. *Notornis*, 42, 138-139.

Barlow, N. D. (1991). A spatial aggregated disease/host model for bovine Tb in New Zealand possum populations. *Journal of Applied Ecology*, 28, 777-793.

Barr, V. (1990). Six steps to smoother product design. *Mechanical Engineering*, 112(11), 48-52.

Basse, B., McLennan, J. A., & Wake, G. C. (1999). Analysis of the impacts of stoats, *Mustela erminea*, on North Island Brown Kiwi, *Apteryx mantelli*, in New Zealand. *Wildlife Research*, 26, 227-237.

Bateman, J. A. (1973). *Animal Traps and Trapping*, London: Newton Abbot Devon.

Beauchamp, A. J., Van Berkum, B., & Closs, M. J. (1998). The decline of the North Island Weka (*Gallirallusaustralis greyi*) at Parekura Bay, Bay of Islands. *Notornis* 45, 31-43.

Becker, S.G. (2008, December 8). *The Animal Welfare Act: Background and Selected Legislation*. Retrieved June 12, 2010, from http://www.nationalaglawcenter.org/assets/crs/RS22493.pdf.

Bennett, G. G., Marczinski, C. A., Murray, K. A., & Whiskin, E. E. (2001) Food Stealing by Young Norway Rats *(Rattus norvegicus). Journal of Comparative Psychology*, 115(1), 16-21.

Binnekamp, H. A., & Ingenbleek, T. M. (2006). Market barriers to welfare product innovations. *NJAS Wageningen Journal of Life Sciences*, 54(2), 1-10.

Biosecurity New Zealand (2008, August 10).*Glueboard Traps*. Retrieved from Biosecurity New Zealand web site: http://www.biosecurity.govt.nz/animal-Welfare/policy/papers/glueboards/index.htm.

Biosecurity New Zealand (2010, June 12). *Animal Welfare Act 1999.* Retrieved from Biosecurity New Zealand web site: http://www.biosecurity.govt.nz/legislation/animal-welfare-act/index.htm.

Blundell, G. M., Kern, J. W., Bowyer, T. R., & Duffy, L. K. (1999). Capturing river otters: A comparison of Hancock and leg-hold traps. *Wildlife Society Bulletin*, 27(1), 184-192.

British Association for Shooting & Conservation (2002). *Codes of practice (BASC)*. Retrieved on 20 September 2010 from http://www.basc.org.uk/*content*/codes.

Brockie, R. (1991). Age structure and mortality of possum *Trichosurus vulpecula.* In B. D. Bell, (Ed.), *First symposium on marsupials in New Zealand, Victoria University, 9-10 May* (pp. 63-83). Wellington, New Zealand

Brown, K., & Alterio, N. (1996). Secondary poisoning of ferrets (Mustela *furo)* and poisoning of other mammalian pests by anticoagulant poison biodifacoum. *The Royal Society of New Zealand Miscellaneous Series*, 36, 34-37.

Brown, K., Innes, J., & Shorten, R. (1993). Evidence that possums prey on and scavenge bird's eggs, birds and mammals. *Notornis* 40, 169-177.

Brown, S. (2001). *The Behavioural Response of Stoats (Mustela erminea) to Trapping Tunnels*. Masters thesis, Lincoln University, Lincoln, New Zealand.

Calcy, P. (1996). The efficacy of trapping for reduced ferret abundance. *The Royal Society of New Zealand Miscellaneous Series*, 36, 73.

Christie, J. A., Westbrooke, I., & Murphy, E. (2003). *Improving stoat trapping efficiency: a pilot study exploring the usefulness of existing data sets.* Department of Conservation, Wellington, New Zealand, (Unpublished pp. 28).

Clapperton, B. K. (2001). Advances in New Zealand mammalogy 1990-2000: Feral ferret. *Journal of The Royal Society of New Zealand*, 31(1), 185-203.

Clapperton, B. K., Phillipson, S. M., & Woolhouse, A. D. (1994). Field trials of slow release synthetic lures for stoats (Mustela *erminea)* and ferrets (*Mustela furo)*. *New Zealand Journal of Zoology*, 21, 279-284.

Clayton, V., & Lenox, V. (2006). *The ferret sholder*. Retrieved April, 2006, from www.baa.duke.edu/companat/sholder/ferret/ferret%20sholder.htm.

Cohen, J. (1969). *Statistical Power Analysis for the Behavioural Sciences*. New York: Academic Press.

Cohen, J. (1992). Statistical Power Analysis. *Current Directions in Psychological Science*, 1(3), 98-101.

Connolly, G. (1988). M-44 Sodium Cyanide Ejectors in the Animal Damage Programme 1976-1986. In A. C. Crabb & R.E. Marsh (Eds.), *Proceedings of the Thirteenth Vertebrate Pest Conference, Monterey, 1-3 March* (pp. 1-8). California, United States of America.

Cook, L., Novak, M., & Weller, L. (1973). *Effectiveness of some furbearer animal traps.* Ontario Ministry of Natural Resources, Toronto, Ontario, Canada.

Cook, M. (2008, August 2). Deaths Spark call for poison drop review. Otago Daily Times. Retrieved from www.odt.co.nz/your-town/wanaka/15975/deaths-spark-call-poison-drop-review.

Cowan, P. E. (1990). Brushtail possum. In C. M. King (Ed.), *The handbook of New Zealand mammals*, (pp. 68-98). Auckland: Oxford University Press.

Cowan, P. E. (2000). Possum biocontrol: prospects for fertility regulation. *Reproduction, Fertility and Development*, 8, 655-660.

Cowan, P. E., & Clout, M. N. (2000). Possum on the move: Activity Patterns, Home range and Dispersal. In T.L. Montague (Ed.), *The Bushtail Possum* (pp24-34*).* Lincoln: Manaaki Whenua Press.

Cowan, P. E., & Tyndale-Bisco, C. H. (1997). Australian and New Zealand Mammal species considered to be a pest or problems. *Reproductive Fertility and Development*, 9, 27-36.

Crawley, M. C. (1973). A live-trapping study of Australian brush-tailed possums, *Trichosurus vulpecula* (Kerr), in the Orongorongo Valley, Wellington, New Zealand. *Australian Journal of Zoology*, 21, 75-90.

Cross, M., Smale, A., Bettany, S., Numata, M., Nelson, D., Keedwell, R., & Ragg, J. R. (1998). Trap Catch as a relative index of ferret (*Mustela furo*) abundance in a New Zealand pastoral habitat. *New Zealand Journal of Zoology*, 25, 65-71.

Department for Enviroment Food and Rural Affairs (2005). *Defra code of practice on the use of snares in fox and rabbit control*. Retrieved 18 September, 2010, from hppt/www.defra.gov.uk/wildlife-pets/wildlife/management/pest-control/snares.htm

Department of Conservation and Ministry for the Environment (2000). *New Zealand's Biodiversity Strategy*. Department of Conservation and Ministry for the Environment Wellington, New Zealand.

Darrow, P. A., Skirpstunas, R. T., Carlson, W. S., & Shivik, J. A. (2009). Comparison of injuries to cotote from 3 types of cable foot-retraints. *Journal of Wildlife Management*, 73(8), 1441-1444.

Dick, B. (1998). *Action Research and Evaluation. Innovation in Evaluation and Programme Developement, On-line conference*. Retrieved May, 2007, from http://www.scu.edu.au/schools/gcm/ar/arp/arphome.html.

Dick, B. (2000). *Resource Papers in Action Research*. Retrieved April 4, 2009, from http://www.scu.edu.au/schools/gcm/ar/arp/ppar.html.

Dilks, P., & Lawrence, B. (2000). The use of poison eggs for the control of stoats. *New Zealand Journal of Zoology*, 27, 173-182.

Dilks, P., O'Donnell, C. F. J., Elliot, G. P., & Phillipson, S. M. (1996). The effect of bait type, tunnel design, and trap position on stoat control operations for conservation management. *New Zealand Journal of Zoology*, 23, 295-306.

Dix, G. I., Jolly, S. E., Bufton, L. S., & Gardiner, A. I. (1994). The potential of electric shock for the humane trapping of bushtail possums, *Trichosurus vulpecula. Wildlife Research*, 21, 49-52.

Dowding, J. E., & Murphy, E. (1996). Predation of Northern New Zealand Dotterels (*Charadrius obscurus aquilonius*) by stoats. *Notornis*, 43(3), 144-146.

Earle, R., Lunning, D., Tuovila, V., & Shivik, J. A. (2003). Evaluating injury mitigation and performance of #3 Victor Soft Catch traps to restrain bobcats. *Wildlife Society Bulletin*, 31, 617-629.

Eason, C. T., & Jolly, S. E. (1993). Anticoagulant effects of pindone in the rabbit and Australian bushtail possum. *Wildlife Research*, 20, 371-374.

Eekeles, J. (2002). On the logic and methodology of engineering design. *Chemical Engineering Research and Design*, 80(6), 615-624.

Eggleston, J. E., Rixecker, S. S., & Hickling, G. J. (2003). The role of ethics in the management of New Zealand's wild mammals. *New Zealand Journal of Zoology*, 30(4), 361-176.

Engeman, R. M. (1982). A comparison of injuries to leg-hold trapped and foot-snared red foxes. *Journal of Wildlife Management*, 46, 113-117.

Eschenbach, T.G., & McKeague, L. S. (1989). Exposition on using graphs for sensitivity analysis. *The Engineering Economist*, 34(4), 315-333.

Fall, M. W. (2002). The Search for Acceptable Animal Traps. In R. M. Timm & R. H. Schmidt (Eds.), *Proceedings 20th Vertebrate Pest Conference, Reno, 4-7 March 2002* (pp. 371-377). Nevada, United States of America.

Fernandez-Moran, J., Saavedra, D., & Mateca-Vilanova, X. (2002). Reintroduction of Eurasian otter (*Lutra lutra*) in northern Spain: trapping, handling, and medical management. *Journal of Zoo and Wildlife Medicine*, 33, 222-227.

Finn, L. (1997). *Conflicting interests of animal and indigenous peoples*. *Trapped by Furs*. Erasmus University, Rotterdam. Retrieved September, 2009, from http://www.highnorth.no/Library/Ethics/co-in-of.htm.

Fitzgerald, B. M., Efford, M. G., & Karl, B. J. (2004). Breeding of house mice and mast seeding of southern beeches in the Orongorongo Valley, New Zealand. *New Zealand Journal of Zoolog*y, 31, 167-184.

Fitzgerald, G., Saunders, L., & Wilkinson, R. (1996). *Public perceptions and issues in the present and future management of possums*. MAF Policy Technical Paper 96/4. Retrieved April, 2007, from http://www.maf.govt.nz/mafnet/rural-nz/research-and-development/pest-control/public-perceptions-of-possum-management/.

Flannery, T. F. (1994). *The future eaters: an ecological history of the Australasian lands and People.* Chatswood, N.S.W: Reed Books.

Fleming, P. J. S., Allen, L. R., Berghout, M. J., Meek, P. D., Pavlov, P. M., Stevens, P., Strong, K., Thompson, J. A., & Thomson, P. C. (1998). The performance of wild-canid traps in Australia: efficiency, selectivity and trap-related injuries. *Wildlife Research*, 25, 327-338.

Flood, R. L. (1998). Action research and management sciences. *Systemic Practice and Action Research* 11(1), 79-100.

Foteenkov, V. A., Korotkov, A. I., Ermolaev, B. S., & Sulimov, A. A. (1982). Propagation of convective combustion in poured density explosives. *Combustion, Explosives, and Shock Waves*, 18(2), 250-252.

Fox, C. H. (2006). Trap Testing An International Perspective. *Animal Issues 2006*. Retrieved January, 2008, from http://www.infurmation.com/pdf/TrapTesting_AISpring06.

Frank, L., Simpson, D., & Woodroffe, R. (2003). Foot snares: an effective method for capturing African lions. *Wildlife Society Bulletin*, 31, 309-314.

Frantz, S. C., & Padula, C. M. (1983). A Laboratory Test Method For Evaluation the Efficacy of Glueboards for Trapping House Mice. In D.E. Kaukeined (Ed.), *Vertebrate Pest Control and Management Materials: Fourth Symposium, ASTM STP 817, Monterey, 26 February 1982* (pp. 209-225). California, United States of America.

Fraser, W. (2001). Introduced wildlife in New Zealand a survey of general public views. *Landcare Research Science Series 23*. Manaaki Whenua Landcare Research Limited, Lincoln, New Zealand.

Freeland, W. J., & Winter, J. W. (1975). Evolutionary consequences of eating *Trichosurus vulpecula* (Masupialia) and the genus *Eualyptus*. *Journal of Chemincal Ecology*, 1, 439-455.

Freeman, C. (1982). *The Economics of Industrial Innovation*. London: Frances Pinter.

Frence, M. J. (1988). *Invention and evolution: design in nature and engineering*. New York: Cambridge University Press.

Gerstell, R. (1985). *The steel trap in North America.* Harrisburg, Pennsylvania: Stackpole Books.

Gerrodette, T. (1987). A Power analysis for Detecting Trends. *Ecology*, 68(5), 1364-1372.

Gentile, J. R. (1983). *The evolution and geographical aspects of the anti-trapping movement: a classic resource conflict.* Doctoral thesis, Oregon State University, Corvallis, United States of America.

Gill, B., & Martinson, P. (1991) *New Zealand extinct birds*. Auckland: Random Century New Zealand Ltd.

Gillies, C. A. (1998). *Aspects of the ecology and management of small mammalian predators in northern New Zealand*. Doctoral Thesis, Auckland University, Auckland, New Zealand.

Gillies, C. A., & Pierce, R. J. (1999). Secondary poisoning of mammalian predators during possum and rodent control operations at Trounson Kauri Park, Northland, New Zealand. *New Zealand Journal of Zoology*, 23, 183-192.

Goodrich, J. M., Kerley, L.L., Schleyer, B. O., Miquelle, D. G., Quigley, K. S., Smirnov, Y. N., Nikolaev, I. G., Quigley, H. B., & Hornocker, M. G. (2001). Capture and chemical anaesthesia of Amur (Siberian) tigers. *Wildlife Society Bulletin,* 29, 533-542.

Green, W. D. (1984). A review of ecological studies relevant to management of the common bushtail possum. In A. P.Smith & I. D. Hume (Eds.), *Possums and gliders* (pp. 483-499). Chipping Norton, N.S.W: Surrey Beatty.

Gregory, N. G. (2003). Assessing the humaneness of pest control methods. In Solutions for achieving humane vertebrate pest control. In B. Jones (Ed.), Proceedings *Royal Society for the Prevention of Cruelty to Animals (RSPCA) Australia Scientific Seminar Canberra, 25 February 2003* (pp. 66-85). Canberra, Australia.

Guthery, F. S., & Beasom, S. L. (1977). Responses of game and nongame wildlife to predator control in South Texas. *Journal of Range Management*, 30, 404-409.

Hart, E., & Bond, M. (1995). *Action Research for Health and Social Care: A Guide to Practic*. Buckingham: Open University Press.

Hellwig, R., & Drummond, D. (1994). *Trap Patents*. Hellwig's Eigenverlag, Lank-Latum, Germany.

Henning, J., Heuer, C., & Davies, P. R. (2005). Attitudes of New Zealand farmers to methods used to control wild rabbits. *Preventive Veterinary Medicine,* 67(2), 171-194.

Henderson, R. J., Brown, J. A., Thomas, M. D., & McAuliffe, R. J. (1999). Use of ground-level or elevated bait stations for possum. In A. Rahman (Ed.), *Proceeding of the 52nd Plant Protection Conference, Auckland, 9-12 August 1999* (pp. 130-135). Auckland, New Zealand.
Retrieved January, 2007, from http://www.nzpps.org/journal/52/nzpp52.php#s1.

Heron, J. (1985). The Role of Reflection in a Co-operative Inquiry. In D. Boud, R. Keogh & D.Walker (Eds.), *Reflection: Turning Experience into Learning* (pp. 128-138). London: Kogan Page.

Hickling, G. J. (1994). Animal Welfare and Vertebrate pest management: compromise or conflict? In R. M. Baker, D. J. Mellor & A. M. Nicol (Eds.), *Animal Welfare in the twenty-first century: ethical educational and scientific challenges: Proceedings of the conference of the Australian and New Zealand Council for the Care of Animals in Research and Teaching (ANZCCART), Christchurch, 23 April 1994* (pp. 119-124). Christchurch, New Zealand.

Hoadley, W. (2003). 1999 plus 4. In L. Carson (Ed.), *Proceedings of the Australian and New Zealand Council for the Care of Animals in Research and Teaching (ANZCCART), Christchurch 18-19 August 2003* (pp. 38-42). Christchurch, New Zealand.

Houben, J. M., Holland, M., Jack, S. W., & Boyle, C. R. (1993). An Evaluation of Laminated Offset Jawed Traps for Reducing Injuries to Coyotes. In R. A. Pierce & F. R. Henderson (Eds.), *Proceedings of The Eleventh Great Planes Workshop, Kansas City 26-29 April 1993* (pp. 47-57). Missouri, United States of America.

Hourigan, C. L., Catterall, C. P., Jones, D., & Rhodes, M. (2008). A comparison of the effectiveness of bat detectors and harp traps for surveying bats in an urban landscape. *Wildlife Research*, 35, 768-774.

Hubert, G. F., Hungerford, L. L., Proulx, G., Bluett, R. D., & Bowman, L. (1996). Evaluation of two restraining traps to capture raccoons. *Wildlife Society Bulletin*, 24(4), 699-708.

Hughes, I. (2000). *Planning Your Action Research Project*. The University of Sydney. Retrieved January, 2005, from www.dol.govt.nz/%5CPDFs%5CDoingActionResearch.pdf.

Iossa, G., Soulsbury, C. D. & Harris S. (2007). Mammal trapping: a review of animal welfare standards of killing and restraining traps. *Animal Welfare*, 16, 335-352.

Innes, J. (1995). The impacts of possum on native fauna. In O'Donnell C.F.J. (Ed.), *Possums as conservation pests. Proceedings of an NSSC Workshop, Wellington, 29-30 November 1994* (pp. 11-15). Department of Conservation, Wellington.

International Association of Fish and Wildlife Agencies (2006). *Best Management Practices for trapping in the United States. IAFWA, Furbearer Resources Technical work group*. Washington, United States of America. Retrieved August 20, 2007, from http://www.fishwildlife.org/Furbearer/Aug%202006%20BMPs/Intro-rev1.pdf.

Jolly, S. E. (1976). Habitat use and movements of the. opossum (Trichosurus vulpeculu) in a pastoral habitat on Banks Peninsula. *New Zealand Ecological Society*, 23, 70-78.

Jones, J. C. (1970). *Design Methods: Seeds of humane futures*. New York: John Wiley and Sons.

Jotham, N. (1987). Research and Development of Humane Trapping Systems. *Conservation*, 11(4), 22-26.

Jotham, N. (1994). *Trap Standards Development – Historical Perspective*. Canadian Association for Humane Trapping (CAHT). Retrieved December, 2008, from http://www.caht.ca/caht/cahttrd.jsp0.

Kamler, J. F., Jacobsen, N. F., & Macdonald, D. W. (2008). Efficiency and safety of Soft Catch traps for capturing black-backed jackals and excluding non target species. *South African Journal of Wildlife Research*, 38(2), 113-116.

Karuppoor, S. S. (2003). *Tools for Innovation and Conceptual Design*. Doctoral thesis, Texas A & M, United States of America.

King, C. M. (1980). Field experiments on the trapping of stoats (*Mustela erminea*). *New Zealand Journal of Zoology*, 7, 261-266.

King, C. M. (1984). *Immigrant killers. Introduced predators and the conservation of birds in New Zealand.* Auckland: Oxford University Press.

King, C. M. (1989). *The Natural History of Weasels and Stoats.* London: Christopher Helm.

King, C. M. (1994). Monitoring and control of mustelids on Conservation lands.Part1: Planning and assessing an operation. *Department of Conservation Technical Series No 3*. Wellington, New Zealand.

King, C. M. (1996). Changing values and conflicting cultural attitudes towards plants and animals in New Zealand. In: B. McFadgen & P. Simpson (Eds.), *Biodiversity*. Papers from the Seminar Series on Biodiversity, Department of Conservation, Wellington, 14 June – 26 July 1994. Wellington. New Zealand. Retrieved September, 2005, from http://bio.waikato.ac.nz/staff/cmking_info.shtml.

King, C. M. (2005). *The Handbook of New Zealand Mammals* (2nd ed.). Auckland: Oxford University Press.

King, C. M., & Moody, J. E. (1982). The biology of the stoat (*Mustela erminea*) in national parks of New Zealand 2. Food Habits. *New Zealand Journal of Zoology*, 9, 57-80.

King, C. M., & Edgar, R. E. (1997). Techniques for trapping and tracking stoats (*Mustela erminea*): a review and a new system. *New Zealand Journal of Zoology*, 4, 193-212.

King, C. M., Flux, M., Innes, J. G., & Fitzgerald, B. M. (1996). Population biology of small mammals in Pureora Forest Park 1: Carnivores (*Mustela ermine, M. furo, M.nivalis,* and *Felis catus*). *New Zealand Journal of Ecology* 20, 241-251.

Kirk, A., & Gillies, C. A. (2008). *Animal Pest Field Trial Report for the efficacy of single set DOC200 traps versus single set Fenn Mk 6 traps set in wooden tunnels in Te Urewera Mainland Island. September 2004-April 2007.* Department of Conservation, Wellington, New Zealand. Retrieved March, 2009, from http://www.predatortraps.com/downloads/doc200_v_mk6fenn.pdf.

Kolbe, J. A., Squires, J. R., & Parker, T. W. (2003). An effective box trap for capturing Lynx. *Wildlife Society Bulletin*, 31, 980-985.

Kurowski, P., & Knopf, G. (2006). Educating Engineers about Product Design Methodology. In B. Chase (Ed.), *Proceedings of 3rd CDEN/RCCI International design conference, University of Toronto, 24-26 July*. (pp 122-130). Toronto, Canada. Retrieved September, 2008, from http://www.designgenerator.com/publications.htm.

Lavers, R. B., & Clapperton, B. K. (1990). Ferret. In King, C. M. (Ed.), *The Handbook of New Zealand Mammals*. Auckland: Oxford University Press.

Levasseur, R. E. (2001). People Skills: Change Management Tools- Lewin's Change Model. *Interfaces*, 31, 71-73.

Lewin, K. (1944). The solution of a chronic conflict in industry. In B. Cooke & J. F. Cox, (Eds.). *Second Brief Psychotherapy Council, Fundamentals of action research* (pp. 3-17). London: Sage.

Lewin, K. (1958). Group Decision and Social change. In E. E. Maccoby, T. M. Newcomb & E. L. Hartley (Eds.). *Readings in Social Psychology* (pp. 340-344). New York: Holt, Rinehart and Winston.

Linhart, S. B. (1985). Furbearer management and the steel foothold trap. In D. B. Farge (Ed.).*Great Plains Wildlife Damage workshop Proceedings, University of Nebraska, 3-5 December 1985* (pp. 50-63). Nebraska, United States of America.

Linhart, S. B., & Dasch, G. J. (1992). Improved performance of padded jaw traps for capturing coyotes. *Wildlife Society Bulletin*, 20, 63-66.

Linhart, S. B., Dasch, G. J., Male, C. B., & Engeman, R. M. (1986). Efficiency of unpadded and padded steel foothold traps for capturing coyotes. *Wildlife Society Bulletin*, 14, 211-218.

Littin, K. E., & Mellor, D. J. (2005). Strategic animal welfare issues, ethical and animal welfare issues arising from the killing of wildlife for disease control and environmental reasons. *Scientific and Technical Review - International Office of Epizootics*, 24(2), 767-782.

Littin, K. E., Mellor, D. J., Warburton, B., & Eason, C. T. (2004). Animal welfare and ethical issues related to the humane control of vertebrate pests. *New Zealand Vetinary Journal*, 52(1), 1-10.

Livingston, P. G. (1996). Overview of the Ferret problem. Ferrets as Vectors of Tuberculosis and Threats to Conservation. *The Royal Society of New Zealand Miscellaneous Series*, 36, 2-6.

Lloyd-Jones, J. (2004). *Comparison of the efficacy of Thumper and Victor Snap Traps on Capture of Ship Rats*. Diploma Conservation and Environmental Management, Northland Polytechnic, Whangarei. New Zealand.

Logan, K. A., Sweenor, L. L., Smith, J. F., & Hornocker, M. G. (1999). Capturing pumas with foot-hold snares. *Wildlife Society Bulletin*, 27, 201-208.

Marks, C. A. (1999). Ethical issues in vertebrate pest control can we balance the welfare of individuals and ecosystems? In D. J. Mellor and V. Momamy (Eds.), *The use of wildlife for research: Proceedings of the Australian and New Zealand Council for the Care of Animals in Research and Teaching (ANZCCART), Western Plains Zoo, 26-27 May 1999* (pp. 79-89) Dubbo, Australia.

Marks, C. A., Allen, L., Gigliotti, F., Busana, F., Gonzalez, T., Lindeman, M., & Fisher, P. M. (2004). Evaluation of the tranquilliser trap device (TTD) for improving the humaneness of dingo trapping. *Animal Welfare*, 13(4), 393-399.

Manthorpe, D. (1981). Incorporating society's concerns into trapping systems: progress on an immediate challenge. *Trans. North American Wildlife Natural Resource Conference*, 44, 319-325.

Mason, G. J., & Litten, K. E. (2003). The humaneness of rodent pest control. *Animal Welfare*, 12(1), 1-37.

McDonald, R. A., & Lariviere, S. (2001). Diseases and pathogens of *Mustela* spp., with special reference to the biological control of introduced stoat *Mustela erminea* populations in New Zealand. *Journal of The Royal Society of New Zealand*, 31(4), 721-744.

McNew, L. B., Nielsen, C. K., & Bloomquest, C. K. (2007). Use of snares to live-capture beavers. *Human – Wildlife Conflicts*, 1(1), 106-111.

Medina-Vogel, G., Hickling, G. J., & Clapperton, B. K. (2000). Assessing spatial activity in captive feral ferrets, *Mustela furo L*. (Carnivora: Mustelidae). *The Royal Society of New Zealand*, 27, 75-83.

Meek, P. D., Jenkins, D. J., Morris, B., Ardler, A. J., & Hawksby, R. J. (1995). Use of two humane leg-hold traps for catching pest species. *Wildlife Research*, 22, 733-739.

Meenken, D. R., & Booth, D. R. (1997). The risk to dogs of poisoning from sodium monofluoroacetate (1080) residues in possum (*Trichosurus vulpecula*). *New Zealand Journal of Agricultural Research*, 40, 573–576.

Meens, J. (2010, April 8). Rare Lizard caught in trap. Retrieved from www.stuff.co.nz/manawatu-standard/news/national-news/3611058/Rare-lizard-killed-in-trap.

Medina-Vogel, G., Hickling, G. J., & Clapperton, B. K. (2000). Assessing spatial activity in captive feral ferrets, Mustela furo L. (Carnivora: Mustelidae). *The Royal Society of New Zealand*, 27, 75-83.

Miller, C. J. (1993). An evaluation of two possum trap types for catch-efficiency and humaneness. *Journal of The Royal Society of New Zealand*, 23, 5-11.

Miller, C., & Elliot, M. (1997). Experimental stoat control North Okarito Forest, West Coast. In Sim J. & A. Sanders (Eds.), *National predator management workshop, 21-24 April St Arnaud.* (pp. 19-23). Department of Conservation, Wellington, New Zealand.

Miller, N. (2003). Paired trial of fresh and long-life stoat baits in a warm, coastal environment. *DOC Science Internal Series 100*. Department of Conservation, Wellington, New Zealand.

Moller, H., & Alterio N. (1999). Home range and spatial organisation of stoats (*Mustela erminea*), ferrets (*Mustela furo*) and feral house cats (*Felis catus*) on coastal grasslands, Otago Peninsula, New Zealand: Implications for yellow eyed penguin (*Megadyptes antipodes*) conservation. *New Zealand Journal of Zoology*, 26, 165-174.

Moller, H., McKinlay, B., Alterio N., & Ratz, H. (1992). Control of mustelids and cats to protect yellow-eyed penguins. In D. Veitch, M. Fitzgerald, J. Innes, E. Murphy. (Eds.), *Proceedings of the National Predator Management Workshop, 13-16 April Craigieburn,* (pp. 54-55). Department of Conservation, Threatened species Unit, Occasional Publication 3, Wellington, New Zealand.

Moller, H., Norbury, G., & King, C. M. (1996). Ecological and behavioural constraints to effective control of ferrets (*Mustela furo). The Royal Society of New Zealand Miscellaneous Series*, 36, 54-68.

Moller, H., Ratz, H., & Alterio, N. (1995). *Protection of yellow-eyed penguins (Megadyptes antipodes) from predators*. Unpublished Wildlife Management Report 65, University of Otago, Dunedin, New Zealand.

Moller, H., Sowers, J., & Wright, M. (1996). Sodium monofloroacetate (1080) poisoned jam bait laid for bushtail possums (*Trichosurus vulpecula)* also kills ferrets (*Mustela furo*). *New Zealand Journal of Zoology*, 23, 135-141.

Montabert, C., & McCrickard, D.S. (2008, January 19). Task Models, Scenarios, and Critical Parameters: Toward the Establishment of an Effective Infrastructure for Reuse-centric Requirements Analysis. Retrieved from http://people.cs.vt.edu/~mccricks/papers/mm06-citsa.pd.

Montague, T. L. (2000). *The Brushtail Possum: Biology, Impact and Management of an Introduced Marsupial*. Lincoln, New Zealand: Manaaki Whenua Press.

Moorhouse, R., Greene, T., Dilks, P., Powlesland, R., Moran, L., Taylor, G., Jones, A., Wills, D., Pryde, M., Fraser, I., August, C., & August, A. (2002). Control of introduced mammalian predators improves kaka (*Nestor meridionalis*) breeding success: Reversing the decline of a New Zealand parrot. *Biological Conservation* 110, 33-44.

Moors, P. J., & Lavers, R. B. (1981). Movements and home range of ferrets (Mustela furo) at Pukepuke Lagoon. *New Zealand Journal of Zoology*, 8, 413-423.

Moran, T. P., & Carroll, J. M. (1996). *Overview of design rationale. Design Rationale: concepts, Techniques, and Use*. Mahwah, New Jersey: Lawrence Erlbaum Associates.

Morgan, D. R. (1982). Field acceptance of non-toxic and toxic baits by populations of the bushtail possum (*Trichosurus vulpecula). New Zealand Journal of Ecology,* 5, 36-43.

Morgan, D. R. (1990). Behavioural response of brushtail possums, *Trichosurus vulpecula,* to baits used in pest control. *Australian Wildlife Research*, 17, 601-613.

Morris, M. C., & Weaver, S. A. (2003). Ethical issues associated with possum research and control in New Zealand. *Journal of Agricultural and Environmental Ethics*, 16(4), 367-385.

Morriss, G. A., Warburton, B., & Rusco, W. A. (2000). Comparison of the capture efficiency of a kill-trap set for bushtail possums that excludes ground birds, and ground set leg-hold traps. *New Zealand Journal of Zoology*, 27, 201-206.

Mowat, G., Slough, B. G., & Rivard, R. (1994). A comparison of three live capturing devices for Lynx: capture efficiency and injuries. *Wildlife Society Bulletin*, 22, 644-650.

Munoz-Igualada, J., Shivik, J. A., Dominguez, F. G., Lara, J., & Gonzalez, L. M. (2008). Evaluation of Cage-Traps and Cable Restraint Devices to Capture Red Foxes in Spain. *Journal of Wildlife Management*, 72(3), 830-836.

Munoz-Igualada, J., Shivik, J.A., Dominguez, F. G., Moreno, A. A., Olalla, M. F., & Garcia, C. A. (2010). Traditional and New Cable Restraint Systems to Capture Fox in Central Spain. *Journal of Wildlife Management*, 74(1), 181-187.

Murphy, E. (1992). An Introduction to mustelids in New Zealand. In D. Veitch, M. Fitzgerald, J. Innes & E. Murphy (Eds.), *Proceedings of the National Predator Management Workshop, Craigieburn, 13-16 April 1992* (pp. 45-48). Canterbury, New Zealand.

Murphy, E. (1996). Ferrets as threats to conservation values. *The Royal Society of New Zealand Miscellaneous Series*, 36, 48-51.

Murphy, E., & Fechney, L. (2003). What's happening with stoat research? Fifth report on the five year stoat research programme, Department of Conservation, Wellington.

Murphy, E., Robbins, L., Young, J. B., & Dowding, J. E. (1999). Secondary Poisoning of Stoats. *New Zealand Journal of Ecology*, 23(2), 175-182.

Muth, R. M., Zwick, R. R., Mather, M. E., Organ, J. F., & Daigle, J. J. (2006). Unnecessary source of pain and suffering or necessary management tool: Attitudes of conservation professionals toward outlawing leghold traps. *Wildlife Society Bulletin*, 34(3), 706-715.

Newcombe, W. R. (1981). The mechanics of spring-powered animal traps. In J. Chapman & D. Pursley (Eds.), *Proceedings of the worldwide furbearer conference, Frostburg, 3-11 August 1981* (pp. 1612-1629). Maryland, United States of America.

Norbury, G. (2000). The potential for biological control of stoats (*Mustela erminea*). *New Zealand Journal of Zoology*, 27, 145-163.

Norbury, G., & Heyward, R. (1996). The response of ferrets to rabbit control. Ferrets as Vectors of Tuberculosis and Threats to Conservation. *The Royal Society of New Zealand Miscellaneous Series*, 36, 30-33.

Nordblom, T., Pannell, D.J., Christiansen, S., Nersoyan, N., & Bahhady, F. (1994). From weed to wealth? Prospects for medic pastures in Mediterranean farming systems of northwest Syria. *Agricultural Economics*, 11, 29-42.

Novak, R. M. (1981). The foot snare and the leg-hold traps: a comparison. In J. A. Chapman, & D. Pursley (Eds.), *Proceedings of the Worldwide Furbearer Conference, Frostburg, 3-11 August 1981* (pp. 1671-1685). Maryland, United States of America.

Novak, R. M. (1987). Traps and trap research. In Novak, M. and Baker J. A., Obbard, M. E., Malloch, B. (Eds.). *Wild furbearer management and conservation in North America* (pp. 145-152). Ministry of Natural Resources and Ontario Trappers Association, Ontario, Canada.

Novak, R. M., & Paradiso, J. L. (1983). *Walkers mammals of the world.* Baltimore, USA: John Hopkins University Press.

O'Donnell, C. F. J. (1996). Predators and the decline of New Zealand forest birds: an introduction to the hole-nesting bird and predator programme. *New Zealand Journal of Zoology*, 23, 213-220.

O'Donnell, C. F. J., Dilks, P., & Elliott, G. P. (1996). Control of a stoat (Mustela *erminea*) population irruption to enhance mohua (yellowhead) (*Mohoua ochrocephala*) breeding success in New Zealand. *New Zealand Journal of Zoology*, 23, 279-286.

Ogilvie, S. C., Thomas, M. D., Morriss, G. A., Morgan, D. R., & Eason, C. T. (2000). Investigation of sodium monofluoroacetate (1080) bait shyness in wild brushtail possum (*Trichosurus vulpecula*) populations. *International Journal of Pest Management*, 46, 77-80.

Olsen, G. H., Linhart, S. B., Holmes, G. J., & Male, C. B. (1986). Injuries to coyotes caught in padded and unpadded steel foothold traps. *Wildlife Society Bulletin*, 14, 219-223.

Olsen, G. H., Linscombe, R. G., Wright, V. L., & Holmes, R. A. (1988). Reducing injures to terrestrial furbearers by using padded foot hold traps. *Wildlife Society Bulletin*, 16, 303-307.

Orwell, J. (1945). *Animal Farm*. London: Secker and Warburg.

Parkes, J., & Murphy, E. (2003). Management of introduced mammals in New Zealand. *New Zealand Journal of Zoology*, 30, 335-359.

Parkes, J., & Murphy, E. (2004). Risk assessment of stoat control methods for New Zealand. *Science for Conservation 237*. Department of Conservation. Wellington, New Zealand.

Parsaei, H. R., & Sullivan, W. G. (1993). *Concurrent Engineering Contemporary Issues and Modern Design Tools*. London: Springer.

Phillips, R. L., Blom, F. S., & Dasch, G. J. (1992). *Field evaluation of three types of coyote traps*. Retrieved October, 2006, from http://digitalcommons.unl.edu/cgi/viewcontent.cgi?article=1060&context=vpc15.

Phillips, R. L. (1996). Evaluation of 3 types of snares for capturing coyotes. *Wildlife Society Bulletin*, 24, 107-110.

Phillips, R. L., & Mullis, C. (1996). Expanded field testing of the No. 3 Victor Soft Catch® trap. *Wildlife Society Bulletin*, 24(1), 128-131.

Pierce, R. J. (1996). Impacts of ferrets on North Island brown kiwi and brown teal. *The Royal Society of New Zealand Miscellaneous Series*, 36, 47.

Pannell, D.J. (1997). Sensitivity analysis of normative economic models: Theoretical framework and practical strategies. *Agricultural Economic*, 16, 139-152.

Poelker, R. J., & Hartwell, H. D. (1973). *Black bear of Washington*. Biological Bulletin 14. Washington State Game Department. Washington, United States of America.

Poggenphol, S., & Sato, K. (2003). Models of Dissertation Research in Design. Retrieved September 2006 from http://www.id.iit.edu/141/documents/tsukuba_2003.pdf.

Poutu, N., & Warburton, B. (2003). Evaluation of the effectiveness of the Waddington backcracker trap for killing stoats. *DOC Science Internal Series 132*. Department of Conservation, Wellington, New Zealand.

Poutu, N., & Warburton, B. (2005). Potential killing effectiveness of the Sturgeon rat/stoat trap. *DOC Research & Development Series 203*. Department of Conservation Wellington, New Zealand.

Powell, R. A. (2005). Evaluating welfare of American black bears (*Ursus americanus*) captured in foot snares and in winter dens. *Journal of Mammalogy*, 86, 1171-1177.

Powell, R. A., & Proulx, G. (2003). Trapping and Marking Terrestrial Mammals for Research: Integrating Ethics, Performance Criteria, Techniques, and Common Sense. *Institute for Animal Research Journal*, 44(4), 259-276.

Pracy, L. T. (1974). Introduction and liberation of the possum *(Trichosurus vulpecula)* into New Zealand. *New Zealand Forest Service Information Series 45*. Wellington, New Zealand.

Proulx, G., & Barrett M. W. (1991a). Ideological conflict between animal rightists and wildlife professionals over trapping wild furbearers. In M. Chubb (Ed.), Proceedings *of the North American Wildlife and Natural Resources Conference 56, Blue River, 16-25 August* (pp. 387–399). Oregon, United States of America.

Proulx, G., & Barrett, M. W. (1991b). Evaluation of the Bionic trap to quickly kill mink (*Mustela vison*) in simulated natural environments. *Journal of Wildlife Diseases*, 27(2), 276-280.

Proulx, G., & Barret, M. W. (1993). Evaluation of mechanically improved Conibear-220® traps to quickly kill fisher (*Martes pennanti*) in simulated natural environments. *Journal of Wildlife Diseases*, 29, 317-323.

Proulx, G., & Barret, M. W. (1994). Ethical considerations in the selection of traps to harvest martens and fishers. In S. W. Buskirk, A. S. Harestad, M. G. Raphael & R. A. Powell (Eds). Martens, Sables and Fishers: Biology and Conservation. Ithaca, Cornel University, 192-196.

Ragg, J. R. (1997). *Tuberculosis (Mcybacterium bovis) epidemiology and ecology of ferrets (Mustela furo) on New Zealand farmland.* Doctoral thesis, University of Otago, Dunedin, New Zealand.

Ragg, J. R., Moller, H., Waldrup, K. A., & MacKintosh, C. (1995). Ferrets (*Mustela furo*) and bovine tuberculosis (*Mycobacterium bovis*); the need for a multi-species. In J. F. T. Griggin, & G. deLisle (Eds.), *Tuberculosis in Wildlife and domestic animals: Proceedings of the Otago Conference Series 3, University of Otago, 19-21 August,* (pp. 291-295). Dunedin, New Zealand.

Ragg, J. R., Rohloff, B., Glover, K., Walker, R., & Bayley, J. (2007). *Possum and ferret traps.* Animal Health Board, Wellington, New Zealand.

Rapoport, R. N. (1970). Three dilemmas in Action Research, with special reference to the Tavistock Experience. *Human Relations*, 23(6), 499-513.

Rate, S. (2008, December 3). FW662 Lecture 7 – Compensatory mortality 1 Lecture 7. *Retrieved August, 2009, from www.colostate.edu/Dept/coopunit/FW662/Lectures/Lecture%207%20Compensatory%20mortality.pdf.*

Ratz, H. (2000). Movements by stoats (*Mustela erminea*) and ferrets (M.Furo) through rank grass of yellow-eyed penguin (*Megadyptes antipodes*) breeding areas. *New Zealand Journal of Zoology*, 27, 57-69.

Reagan, S. R., Ertel, J. M., Stinson, P., Yakupzack, P., & Anderson, D. (2002). A passively triggered foot snare design for American black bears to reduce disturbance by non-target animals. *Ursus*, 13, 317-320.

Regan, T. (1985). The Case for Animal Rights, in Singer, P. (Ed.). *In Defence of Animals* (pp.13-26). Oxford: Basil Blackwell.

Richards, R. T., & R. S. Krannich. (1991). The ideology of the animal rights movement and activist's attitudes toward wildlife. In R. E. McCabe (Ed.), *Proceedings of the 56th North American Wildlife and Natural Resources Conference, Edmonton, 17-22 March 1991* (pp. 363-371). Edmonton, Canada.

Romanov, O. Y. (1975). The nonstationary combustion rate of gunpowder. *Combustion, Explosion, and Shock Waves*, 11(2), 163-171.

Ross, J. G., & Henderson R. J. (2003). An evaluation of two long-life baits containing diphacinone for the control of ferrets (*Mustela Furo*). *New Zealand Plant Protection, 56, 71-76.*

Roy, L., D., Twitchell, C., & Hiltz, M. (2006). Factors Influencing the Effectiveness of Breakaway Snares to Capture Coyotes and Release Deer in Alberta. Retrieved 8 September, 2010, from www.assembly.ab.ca/lao/library/egovdocs/2006/alrc/154175.pdf.

Rudolph, S. (1995). *A Methodology for Schematic Evaluation of Engineering Design Objects*. (Doctoral thesis, Stuttgart University, 1995). Retrieved from hppt//citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.49.

Rudolph, S., & Hansrudi, N. (2000). Knowledge Enhanced Grammars. In U. Cugini & M. J. Wozny (Eds.), Proceedings of the *IFIP WG5.2 Workshop on Knowledge Intensive C on Engineering Design Generation with XML-based AD, Parma, May 20-24* 2000 (pp. 213-226). Parma, Italy.

Sahr, D. P., & Knowlton, F. F. (2000). Evaluation of Tranquilizer trap device (TTDs) for foothold traps used to catch grey wolves. *Wildlife Society Bulletin*, 28(3), 597-605.

Sanders, M. D. (1997). Video monitoring of banded dotterel nests in braided rivers. In J. Sim & A. Sanders (Eds.), Proceedings of the *Predator Workshop, St. Arnaud, 21-24 April 1997* (pp. 93-98). St. Arnaud, New Zealand.

Sauter, R. F., & Morris, R. S. (1995). Behavioural studies on the potential for direct transmission of tuberculosis from feral ferrets (*Mustela furo*) and possums (*Trichosurus vulpecula*) to farmed livestock. *New Zealand Veterinary Journal*, 43, 294-300.

Scheiner, S.M., & Gurevitch, J. (1993). *Design and Analysis of Ecological Experiments*. London: Chapman & Hall.

Schorger, A. W. (1951). A brief history of the steel trap and its use in North America. *Transactions of the Wisconsin Academy of Science Arts Letters*, 40(2), 171-199.

Schumpeter, J. A. (1934). *The Theory of Economic Development.* Cambrige: Harvard University Press.

Serfass, T. L., Brooks, R. P., Swimley, T. J., Rymon, L. M., & Hayden, A. H. (1996). Considerations for capturing, handling, and translocating river otters. *Wildlife Society Bulletin*, 24, 25-31.

Shivik, J. A., Martin, D. J., Pipas, M. J., Turnan, J., & DeLiberto, T. J. (2005). Initial comparison: jaws, cables, and cage-traps to capture coyotes. *Wildlife Society Bulletin*, 33(4), 1375- 1383.

Shivik, J. A., Gruver, K. S., & DeLiberto, T. J. (2000). Preliminary evaluation of new cable restraints to capture coyotes. *Wildlife Society Bulletin*, 28(3), 606-613.

Skinner, D. L., & Todd, A. W. (1990). Evaluating efficiency of foot holding devices for coyote capture. *Wildlife Society Bulletin*, 18, 166-175.

Shigley, J., Mischke, C., & Budynas, R. (2003). *Mechanical Engineering Design.* New York: Wiley & Sons.

Simms, D. J., & Craig, S. A. (1998). North American weasels: resource utilisation and distribution. *Canadian Journal of Zoology*, 57, 504-520.

Singer, P. (1993). *Practical Ethics.* Cambridge: Cambridge University Press.

Smith, E. M. (2003). From Russia With TRIZ. Mechanical Engineering Design, 1-5. Retrieved September, 2006, from http://www.highbeam.com/doc/1G1-98954042.html.

Smith, G. P., Ragg, J. R., Moller, H., & Waldrup, K. A. (1995). Diet of feral ferrets (*Mustela furo)* from pastoral habitats in Otago and Southland, New Zealand. *New Zealand Journal of Zoology*, 22, 363-369.

Spurr, E. B. (1998). The development of a long-life toxic bait and lures for mustelids. Department of Conservation: Progress in Mammal pest control; on New Zealand conservation lands. *Science for Conservation 127*, 1-24.

Stevens, T., & Barnett, S. (1998). A review of possum monitoring in Waikato Conservancy. Department of Conservation, Wellington. *Conservation Advisory Science Notes,* No 171, 1-22.

Stewart, J. (1977). *Traps and Trapping. Furs and Fashions*. New York: Argus Archives.

Stringer, E. T. (1996). *Action Research: A Handbook for Practitioners*. London: Sage.

Suren, A. (2006). Quantifying contamination of streams by 1080 baits, and their fate in water, *New Zealand Journal of Marine and Freshwater Research*, 40, 159-167.

Taylor, R. H., & Tilley, J. A. (1984). Stoats (*Mustella erminea*) on Adele and Fisherman Islands, Abel Tasman National Park, and other offshore islands in New Zealand. *New Zealand Journal of Zoology*, 7, 139-145.

Tandon, O. P., Malhotra-Tandon, S., & D'Silva, I. (2003). Neurophysiology of pain: insight to orofacial pain. *Indian Journal of Physiology and Pharmacology*, 47, 247-269.

Temme, M., & Jackson, W. B. (1979). Criteria for trap evaluation. *ASTM Technical Publication*, American Society for Testing and Materials, Philadelphia, United States of America.

Thomas, M. D., & Brown, J. A. (2000). Possum monitoring using raised leg-hold traps. Department of Conservation, *Science for Conservation 164*, 1-17. Wellington.

Thomas, M. D., & Warburton, B. (1985). Sleeves or slaying-protecting erosion planting. *Soil and Water*, 21(3), 25-27.

Thomson, C., Warburton, B., & Drew, K. (1999). Kiwi-safe kill traps for possums. *Conservation Advisory Science notes No. 222*, Department of Conservation. Wellington.

Tidd, J., Bessant, J., & Pavitt, K. (2001). *Managing Innovation; Integrating Technological, Market and Organizational Chang.* West Sussex, England: John Wiley & Sons.

Timmins, S. M. (2004). How weed lists help protect native biodiversity in New Zealand. *Weed Science Society of America*, 18(5), 1292-1295.

Travaini, A., Laffittee, R., & Delibes, M. (1996). Leg-hold trapping red foxes (*Vulpes vulpes*) in Donana national park: efficiency, selectivity, and injuries. *Journal of Wildlife Research*, 1, 52-56.

Tullar, B. F. (1984). Evaluation of a padded leg-hold trap for capturing foxes and raccoons. *New York Fish and Game Journal*, 31, 97-103.

van Ballenberghe, V. (1984). Injuries to wolves sustained during live-capture. *Journal of Wildlife Management*, 48, 1425-1429.

Vice, D. S., Enegeman, R. M., & Vice, D. L. (2005). A comparison of three trap designs for capturing brown treesnakes on Guam. *Wildlife Research*, 32, 355-359.

Warburton, B. (1982). Evaluation of seven trap models as humane and catch-efficient possum traps. *New Zealand Journal of Zoology*, 9, 409-418.

Warburton, B. (1992). Victor foot -hold traps for catching Australian bushtail possums in New Zealand: capture efficiency and injuries. *Wildlife Society Bulletin*, 20, 67-73.

Warburton, B. (1998a). The humane trap saga: a tale of competing ethical ideologies. In D. J. Mellor, M. Fisher, G. Sutherland (Eds.), *In proceedings of the Australian and New Zealand Council for the Care of Animals in Research and Teaching (ANZCCART), Wellington, 18-19 November 1998* (pp. 131-137). Wellington, New Zealand.

Warburton, B. (1998b). Evaluation of escape rates by possums captured in Victor No. 1 Soft Catch traps. *New Zealand Journal of Zoology*, 25(2), 99-103.

Warburton B., Poutu N., Peters D., & Waddington, P. (2008). Traps for killing stoats (*Mustela erminea*): improving welfare performance. *Animal Welfare*, 17, 111-116.

Warburton, B., Gregory, N. G., & Morriss, G. (2000). Effect of jaw shape in kill-traps on time to loss of palpebral reflexes in bushtail possums. *Journal of Wildlife diseases*, 36, 92-96.

Warburton, B., & Hall, J. V. (1995). Impact momentum and clamping thresholds for developing standards for possum kill traps. *New Zealand Journal of Zoology*, 22, 39-44.

Warburton, B., & Orchard, I. (1996). Evaluation of five kill traps for effective capture and killing of Australian brushtail possums (*Trichosurus vulpecula*). *New Zealand Journal of Zoology*, 23, 307-314.

Warburton, B., & Poutu, N. (2002). Evaluation of the killing effectiveness of Rat Zapper 2000 for killing rats. *Landcare Research Contract Report LC0102/034*. Manaaki Whenua Landcare Research Ltd. Lincoln, New Zealand.

Warburton, B., & Poutu, N. (2003). Possum escapes from No 1 Leghold Traps: A mechanical Evaluation. *Animal Health Board Report R-10579.* Wellington.

Warburton, B., & Poutu, N. (2008). Effectiveness of chain-springs on leghold traps for reducing injuries to captured brushtail possums (*Trichosurus vulpecula*). *New Zealand Journal of Zoology*, 35, 147-150.

Warburton, B., Poutu, N., & Domigan, I. (2002). Evaluation of the effectiveness of the Victor snapback for killing stoats. Prepared for the Department of Conservation, *Science Internal Series* 83, Wellington, New Zealand.

Ward, A., Liker, J. K., Critiano, J. J., & Sobek, D. K. (1995). The second Toyota paradox: How delaying decisions can make better cars faster. *Sloan Management Review*, 36(3), 43-61.

Whishaw, I. Q., & Boguslaw, P. G. (1996). Food wrenching and dodging: Eating time estimates influence dodge probability and amplitude. *Aggressive Behaviour*, 20(1), 35-47.

Whitfield, I., Coates, G., & Hills, B. (1999). Multi-objective robust concept exploration within the made-to order sector. In B. Launder & N. Sandham (Eds.), Proceedings of the *International Conference on Engineering Design (ICED),* Munich, *12-24 August1999* (pp. 1-6). Munich, Germany.

Whitehead, A. N. (1925). *Science and the Modern World*. New York: The Free Press.

Wilkinson, R., & Fitzgerald, G. (1998). *Public Attitudes to Rabbit Calicivirus in New Zealand*. Lincoln, New Zealand: Manaaki Whenua Press.

Wilson, P. R., Karl, B. J., Toft, B. J., Beggs, J. R., & Taylor, R. H. (1998). The role of introduced predators and competitors in the decline of Kaka (*Nestor meridionalis*) populations in New Zealand. *Biological Conservation*, 82(2), 175-186.

Woodman, N., Timm, R. M., Slade, N. A., & Doonan, T. J. (1996). Comparison of traps and baits for censusing small mammals in neotropical lowlands. *Journal of Mammalogy*, 77(1), 274-281.

Personal Communications

David Blair, Yellow Eyed Penguin Trust, Dunedin.

Robyn Burly, Department of Conservation, Akaroa.

Mike Bygate, Pest control contractor, West Coast.

Grant Crossett, Pest control contractor, Nelson.

Mike Green, Firearms Officer, NZ Police, Wellington.

David Hunter, Pest control contractor, Little River, Canterbury.

Steve Hix, Research manager, Connovation Ltd, Christchurch.

Dr. Elaine Murphy, DOC Research, Christchurch.

Dr. James Ross, Lincoln University, Lincoln.

Robbie Tiffen, Gunsmith, Christchurch.

Julie Turner, Animal Research Manager, Manaaki Whenua Landcare Research Ltd.

Bruce Warburton, Researcher, Manaaki Whenua Landcare Research Ltd.

Ian Woodhead, Electrical Engineer, Lincoln Ventures Ltd., Lincoln.

Appendix A

New Zealand Journal of Zoology, 2008, Vol. 35: 243–250 243
0301–4223/08/3503–0243

Trapping tunnel design incorporating behavioural preferences of stoats

IAN R. DOMIGAN
Natural Resources Engineering Group
Environment, Society and Design Division
PO Box 84
Lincoln University
Lincoln 7647
Canterbury, New Zealand

KENNETH F. D. HUGHEY
Environmental Management Group
Environment, Society and Design Division
PO Box 84
Lincoln University
Lincoln 7647
Canterbury, New Zealand

Abstract Stoats (*Mustela erminea*) are introduced pests in New Zealand, and there is an urgent need for effective trapping systems that kill the animal in a humane manner. A treadle trap was designed, the Dominus trap, that utilised an earlier-proven humane killing system enhanced by the addition of a treadle plate trigger. This system enabled the trap to be classified as a Class A trap under the National Animal Welfare Advisory Committee (NAWAC) guidelines for animal kill traps, by successfully rendering 10/10 animals unconscious within 30 s. The Dominus trap mimics a tunnel, which by its very shape entices the animal to enter, but weighs only 600 g. A trial at Flea Bay, on Banks Peninsula, used 35 Dominus traps placed alternately between 35 Fenn Mk VI traps set over 3150 trap nights (TN). The trial was conducted from March to May 2007 and was repeated for a further 7740 trap nights from January to March 2008, using 20 Dominus traps. The Dominus trap caught stoats consistently at the rate of 0.22 stoats/100 TN in both years, compared with 0 and 0.14/100 TN in Fenn traps, so potentially provides a humane alternative to the Fenn.

Z07050; Online publication date 4 July 2008
Received 3 September 2008; accepted 2 May 2008

Keywords design approach; *Mustela erminea*; stoats; tracking tunnels; traps

INTRODUCTION

The problem

Biodiversity loss is New Zealand's most pervasive environmental problem (DOC & MfE 2000). Introduced mammalian predators (King 1984; Wilson 2004) account for a significant decline in native biota. For many bird species, the key predators are mustelids (*Mustela* spp.), hedgehogs (*Erinaceus europaeous occidentalis*), cats (*Felis catus*) and rats (*Rattus* spp.). Temporary population irruptions of stoats (King 1983) and rats (Dilks et al. 2003), following periodic masting events in southern beech forests (Murphy & Dowding 1995), can lead to significant increases in predation on birds and native bats (Pryde et al. 2006).

The problem of protecting native fauna during these irruptions has been recognised by the Department of Conservation (DOC & MfE) (2000). On offshore islands, the Department of Conservation (DOC) has invested heavily in predator eradication programmes (Cullen et al. 2005), and has achieved positive results (Towns & Broome 2003).

At selected mainland island sites, where predators cannot be eradicated, Operation Ark (a programme managed by DOC) is designed to reduce the damage done at times of critical danger. The main problem is to increase the cost effectiveness of current and developing technologies. The Okarito sanctuary, protecting the Okarito brown kiwi (*Apteryx rowi*), is the most intensively trapped area in New Zealand, but it could not defend the kiwi chicks during a recent period of high risk of stoat predation, so the chicks still had to be removed (DOC unpubl. data). The perceived reason for this failure was that there were at least some stoats resident within the trapping grid that were trap shy (B. Edwards pers. comm.). It is hardly surprising, then, that the development of low-cost and more effective predator traps is a growth area in New Zealand's conservation management.

The increased number of new kill traps now available raises the possibility of comparing one trap type against another to determine catch rate and cost effectiveness in the field. A trap that would be effective against stoats and multiple other species would be of particular interest.

Comparisons between trap types must take into account the new trap testing protocol as proposed by the National Animal Welfare Advisory Committee (NAWAC). The lowest acceptable classification under the Act (Class B) requires that kill traps render a captured animal unconscious within 3 min (Warburton et al. 2008). The highest classification is Class A, which requires that an animal be rendered unconscious within 30 s. The only other classification, Class C, is for those traps that fail to meet the animal welfare testing protocol.

The Animal Welfare Act 1999 requires that Class C restraint traps and all live traps must be cleared daily, within 12 h of sunrise. This requirement severely limits the number of traps that one person can operate, which makes leg hold traps for pest eradication an expensive proposition when compared to humane kill traps.

Fitzgerald et al. (2002) surveyed the attitudes of New Zealanders to pest control, and found that trapping and shooting are regarded as the most acceptable methods of pest control, even though they may not be the most cost effective. Many of the traps traditionally used by DOC have failed the new testing requirements (Warburton et al. 2008). Hence, there is an urgent need to replace them with traps that achieve the same or better catch rates. The long-term implication is that trapping systems should be continually replaced until a universal Class A classification has been achieved.

Until recently the design of most new traps has been based on improving the mechanical attributes of the trap, with little consideration given to the target animal and the cost of installation and baiting. In this paper we report on the importance of tunnel vision in the design of effective traps that will meet the new testing requirements. We review the relevant ecological literature, report on the design method, outline the results of a preliminary trial and discuss their implications including the need for further research.

Ecological considerations for the Dominus trap design

Tunnel shape was identified by King & Edgar (1977) as a natural feature to which stoats (*Mustela erminea*) are attracted. S. Brown (2002) found that stoats are more likely to fully enter "see-through tunnels", open at both ends, as opposed to tunnels that are blind at one end. By contrast, Dilks et al. (1996) found no difference in the catch rate of stoats in single entrance tunnels as opposed to double entry tunnels. Their tunnels were see-through in that one end was restricted only with wire mesh, so there was little difference between double and single entry versions. For the catching of rats, placing the trap on top of a wooden base rather than directly on the ground significantly increased the catch rate (P. Dilks pers. comm.), but partially camouflaged traps were no more effective than visible traps.

Hamilton (2004) compared the catch rate of stoats in Fenn IV traps set inside plastic Philproof tunnels of different colours. The results, suggesting that more stoats were caught in yellow tunnels, should be confirmed by further trials (E. Murphy pers. comm.). For trapping rats, P. Dilks (pers. comm.) found that tunnel colour had no significant effect.

Tracking tunnels are commonly used as a mammalian predator monitoring system (Brown et al. 1996; Innes & Skipworth 1983; Brown & Miller 1998). There is a linear correlation between trapping rate and tracking rates for rats and stoats (Gillies & Dilks 2003). Standardised footprint tracking methods for monitoring stoat populations, based on systems developed by King et al. (1994), have been widely implemented by DOC. The original trapping tunnel ink system (King & Edgar 1977) has been improved and is now commercially available through Connovation Ltd.

Tunnels have also been used to protect birdlife during trials of eggs innoculated with 1080 (Dilks & Lawrence 2000), and tests of animal responses to lures found that the tunnels with a lure were tracked 19 times, whereas those without a lure were only tracked three times. However, there was no way to determine how many of these records were made by the same stoat repeatedly visiting the tunnels (Clapperton et al. 1999).

Hair tubes (Horton et al. 2005) are a recently-developed method of identifying individual stoats running through tunnels. Inside a non-baited 40 mm diameter × 400 mm long PVC tube there is a glue-coated rubber band. The animal has to push under the rubber band, and in so doing it leaves a few hairs caught in the glue. DNA from the hair follicles can be analysed to determine the genetic identity of each visiting animal. The success of this method shows that stoats are prepared to go through relatively small holes without being attracted by a stoat-specific lure, although the glue itself (A. Byron pers. comm.) could possibly have been acting as a lure.

The question about what size of tunnel is naturally attractive to a given target species has not been fully answered in the literature, although rectangular shapes 80 × 90 mm have proved to be a particularly appealing entry size for rats (NZ Patent 245911, held by M. Van Bennekom). Entry size and tunnel shape are usually based mainly on the need to exclude non-target animals, and on the size of the trap to be covered. The style of trap normally determines the tunnel's physical dimensions, and the type of entry is based on which animals need to be excluded. For example, the DOC200 trap needs a large box with a floor, whereas a Fenn trap can be set under an open-floored plastic cover. These different requirements make it difficult to design a single trapping system capable of protecting all non-target species, including native ground predators such as the weka (*Gallirallus australis*).

Traps with large, bulky tunnels are difficult to deploy and service unless they are accessible along tracks. The cost of cutting access tracks can be a significant component of a trap placement (K. P. Brown 2002).

The literature on baits and lures is large but confused. More information is needed comparing visual baits (eggs) with scented (rabbit-based) lures. Montague (2002) and Clapperton et al. (2006) suggest that rabbit meat is the best lure, but comparisons of trapping systems do not always use standardised baits and lures.

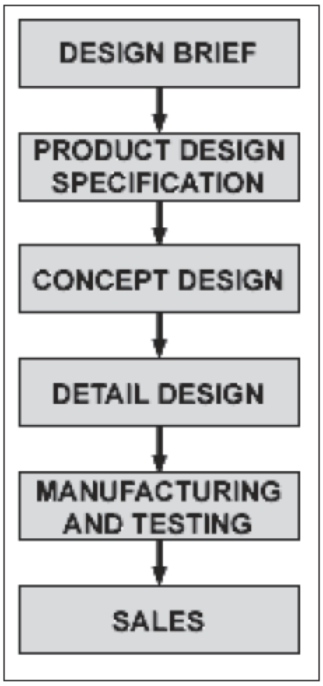


Fig. 1 Product design flowchart.

THE PROCESS OF TRAP DESIGN

Design essentially is an exercise in problem solving. The traditional view envisages a staged sequence from design to manufacture; the outcome of one stage is passed on to the next stage (Fig. 1). Mistakes have to be corrected by reverting to an earlier stage and reiterating the design. A better approach is for the designer to eliminate potential future problems before they arise, by considering the later stages as part of the detailed design brief.

Design brief

The development of an appropriate design brief requires a very good understanding of the practical and ecological issues. For this project, the trap design brief was prepared in conjunction with the Otago and Canterbury conservancies of DOC, and with commercial trappers. The finalised brief developed from these discussions specified that:

- The trap should be small, self-contained, light, and adaptable.
- The killing mechanism should target the head and neck region of the animal.
- Non-target species should be excluded by entry conditions.
- The trap cover should be a tunnel shape, incorporated into the trap rather than being a separate component.
- The tunnels should be see-through, and at least 40 mm wide.

Given the above and the review of relevant ecological literature it is clear the tunnel shape mimics the successful tracking tunnel, exploiting the animal's natural instincts to explore tunnels—the tunnel is therefore the dominant feature in the design.

Product design specifications

The target species for this trap are rats, hedgehogs, ferrets (*Mustela furo*) and stoats, with the primary emphasis on stoats. The ultimate design considerations for the trap, building on the contents of the design brief, were: quick kill, high catch rate, non-rusting trigger system, low trigger pressure,

Fig. 2 Looking through Dominus.

rectangular opening, lightweight, cost effective, easy and safe to set for operator, and easy to clear and re-bait.

Treadles work well as a triggering device in traps, because the animal needs only to enter the tunnel to be caught—it does not need to remove a piece of bait. Traps that require fewer active responses by the animal have a greater chance of catching it. From observations of radio-collared stoats, Dilks & Lawrence (2000) and Jones et al. (2004) showed that animals encountering a trap for the first time may not fully enter it, so it is desirable to set the trigger system as close to the point of entry as possible, whilst still minimising the chances of an escape.

To ensure a consistent strike location leading to a quick kill, the animal must be correctly orientated inside the tunnel. To attract the animal, the tunnel shape must be straight and see-through. To catch animals entering from either end, and to prevent both traps being set off together when one is triggered, a major problem in conventional double sets, the two traps must be placed back to back, physically separated by a 5 mm gap.

Preliminary testing showed that torsion springs lose their strength over time (Domigan unpubl. data). Therefore, most traps using torsion springs to fire the trap, including basic rat-traps, most leg hold traps, the Fenn and many of the new traps on the market, are subject to a persistent failure in design. The issue of these traps losing their strength and potentially failing after passing the NAWAC trap testing protocol is of real concern (Warburton et al. 2008).

From our experience, the human manageability of a trap is often overlooked. Installation, clearing, setting, re-baiting, and ongoing maintenance must be made easy and safe for the trapper.

If the animal has been in the trap for some time, the clearing operation can be quite unpleasant. In conventional traps, removing the catch and cleaning its components requires the trapper to handle parts within the trap's strike range, which introduces the risk of injury to fingers. Some traps require that re-baiting be done with the traps already set; for others, routine maintenance and removal of rust from the trigger may require the trap to be sprung and reset, even though "dry firing" of the traps is not desirable because it will ultimately limit their life. The hand strength required to pry the trap jaws apart makes some traps impossible for many people to set. Special setting tools are required to perform this task for the Warrior, DOC250, Holden possum trap and the Connibear range of traps. The concept of easy replacement parts, a distinct advantage for trap maintenance, is unavailable in any conventional trap.

For remote locations, the installation cost needs to be considered at the design stage. For example, it may be that the trap can be assembled on site so as to save space during transport, or it may be that different materials could be used. The actual longevity of the trap needs to be considered along with the cost of installing and later removing the trap.

THE DOMINUS TRAP

The tunnel trap developed as a result of the above process was called the Dominus (Fig. 2). The outer body or tunnel was made of either 4 mm plastic or 1.6 mm galvanised metal. The advantage of the plastic body was that it would not rust, and all rotating parts had plastic pivot points. The option of using the trap as a single-entry, single-kill device (Fig. 2) by fitting a removable shelled exit door to direct entry from the other end was retained. To maintain the tunnel shape and to mimic a tracking tunnel, the mechanical components were designed to avoid restricting the see-through view.

The trap does not require a cover because it is self-contained. That also helps to make it very light and easily carried (600 g each, compared with 6–10 kg for a DOC200 trap with box). All components can be easily removed, so up to 50 traps, in broken down form, or 20 fully assembled traps, could be carried by one person.

All treadle and trigger components were made of plastic, ensuring that the trigger never rusted and its sensitivity did not change over time. The entrance was designed to encourage the animal to enter by giving it a solid and non-threatening threshold on which to stand firmly at first. The trap was triggered as the animal made its second step onto the treadle plate, releasing the impact bar. The placement of the bottom bolt, which acted like a step, helps to prevent an animal from jumping the treadle plate.

Previous trap design work showed that a 3 mm wide impact bar with a clamp of 10 kg would render the animal unconscious within 30 s, by breaking the skull (I. Domigan unpubl.data). The impact bar of the Dominus trap (Fig. 3) is restrained in a virtually horizontal position by the trigger setting arm. When the trap is set, by pulling a nylon cord, the trigger setting arm locks the system in place by engaging with the treadle plate. When an animal depresses the treadle, the impact bar is released, targeting the animal in the head and neck region and locking it tightly between the impact bar and the bottom bar. The treadle can be set very fine (25 g, a "hair" trigger response) or harder if preferred. To release a dead animal it is necessary only to pull on the cord, which moves the impact bar and allows the carcass to drop from the trap.

Dominus was designed to take advantage of long-life baits, which attract animals using strongly scented cues (as opposed to a visual cue like an egg). Experienced stoat-dog handlers assert that a stoat has a more sensitive nose than a dog. For this style of trap the objective is to attract the animal to the trap, and then rely on the tunnel shape to entice it inside. As new scent-related baits become available, they can be incorporated into the plastic tunnel to provide a slow release mechanism.

Dominus can be pinned to the ground with a log or rock on top, or by the use of metal pins. The bait door provides access to the trap interior, so there is no need to unpin the trap when the bait needs to be changed. The trap is open to the soil underneath, so grass growth within the trap has to be prevented with spray, weed mat, or by attaching the trap to a board.

Trapping configurations can be easily changed, including from single to double sets. Changing to multiple units at one site can be achieved by placing the traps about a central baiting point with separate entries, each with a trap placed in front of it; for example a square central bait cover has four traps, and a hexagon six traps. A flexible trap line on which "hot spots" can be identified, where trapping effort can be concentrated, also makes economic sense.

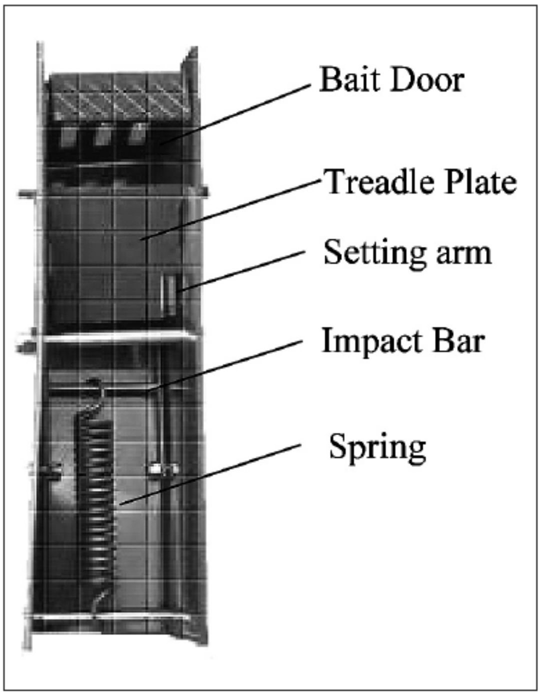


Fig. 3 Dominus single trap components.

TESTING THE DOMINUS TRAP

Pen trial

First, a pen trial was conducted by Nick Poutu of Manaaki-Whenua Landcare Research, Lincoln, under animal ethics approval granted to determine whether the trap impact mechanism met the requirements laid down by the National Animal Welfare Advisory Committee guidelines. With a sample of 10 animals, the testing criteria defining a Class A trap required all 10 to be rendered irreversibly unconscious within 30 s or, for a Class B trap, within 3 min. The results (Table 1) show that all animals received head strikes, and all were unconscious within 30 s. The trap mechanism was therefore classified as Class A under the trap testing guidelines.

When the Dominus trap itself was constructed, it was 10 mm wider than the mechanism and had a treadle trigger as opposed to the push trigger used in the pen trial. Therefore, a field trial was conducted to confirm that the strike location would remain the same in practice, and to calibrate its performance against existing traps used.

Field trials

A preliminary field test of the performance of the Dominus trap was done over 57 days between 10 March and 26 May 2007 at Flea Bay on the Banks Peninsula, Canterbury. Little blue penguins (*Eudyptula minor*) nest along with sooty shearwater (*Puffinus griseus*) colonies at Flea Bay and in adjacent bays. The experimental trap line was located c. 1 km from Flea Bay, and forms part of a protective trapping zone about the penguin and sooty shearwater colonies. The predators most often caught in the area are hedgehog, stoat and feral cat, in that order (R. Burley pers. comm.).

The trapline followed a fence line and a 4WD track through rolling farm land with scattered patches of native bush. Dominus traps were set alternately between 35 existing standard Fenn Mk VI trap sites at 200 m spacing, making a total of 70 double sets (35 of each, 100 m apart, set for 5390 trap nights). The Fenn traps, set under black Philproof tunnels with entrance holes of 60 mm at both ends, had been in place for at least 5 years. The ground under the Dominus traps was sprayed with a glyphoshate herbicide and the traps pegged down. All traps were baited with bacon and rabbit lure, checked every 2 weeks, and rebaited as required.

In 2007 six stoats were caught, all in Dominus traps; Fenn traps caught none. One cat was caught alive in a Fenn trap, held by the paw, and four rabbits, probably juveniles investigating the tunnel, as the bait used rabbit meat/paste.

The trial was repeated in 2008 to increase the sample sizes observed. The trap positions used in the 2007 trial were unfortunately altered by trapping

Table 1 Results of a pen trial to determine classification of the impact mechanism under the National Animal Welfare Advisory Committee (NAWAC) guidelines. Time to loss of palpebral reflex indicates the time to loss of consciousness (minutes:seconds) in the trapped animal.

Date (2003)	Weight (kg)	Sex	Time to loss of palpebral reflex (min:s)	Heart stop (min:s)	Strike location
26 Mar	0.299	Male	<0:30	3:07	Top of skull, just forward of ears; rear jaw.
27 Mar	0.139	Male	<0:30	2:39	Skull, across one ear; rear jaw.
27 Mar	0.300	Male	<0:30	2:20	Top of skull, across ears; rear jaw.
27 Mar	0.242	Male	<0:20	3:31	Top of skull, just forward of ears; rear jaw.
27 Mar	0.206	Male	<0:10	3:10	Top of skull, just forward of ears; rear jaw.
27 Mar	0.197	Female	<0:20	3:20	Just behind eyes; behind jaw + foot.
27 Mar	0.306	Male	<0:20	3:30	Skull, between eyes and ears; rear jaw.
28 Mar	0.265	Male	<0:20	3:24	Skull, between ears and eyes; rear jaw.
28 Mar	0.171	Female	<0:15	3:03	Top of skull, across ears; behind jaw.
28 Mar	0.293	Male	<0:20	1:24	Top of skull, between eyes and ears; rear jaw.

Table 2 Catch rate comparison trial: Dominus versus Fenn.

	Total trap nights	Stoat	Stoats/100 trap nights	Hedgehog	Rabbit	Ferret	Rat	Cat
2007								
Dominus	2695	6	0.22	10	2	0	0	0
Fenn	2695	0	0	13	2	0	0	1
2008								
Dominus	1800	4	0.22	4	1	0	0	0
Fenn	5760	8	0.14	55	0	1	1	0

staff, and 23 of the Dominus traps were replaced by Fenns, Timms and DOC200 traps. Although there were fewer Dominus traps in the field during the second test, the trapping period was longer (90 days). The catch rate in the Dominus trap, 0.22/100 trap nights, was the same in both trial years (Table 2).

All stoats were struck in the target area (head and neck). This trial was therefore useful in confirming that the design of the Dominus was effective in achieving consistently humane kills. The setting of the traps could be very fine but none misfired, and there was no need to "dry fire" for testing in the field.

Because all the traps were baited, and both the Dominus and the Philproof tunnels were open-ended, this trial suggests that the higher catch rate of the Dominus trap might have been due to its fine trigger mechanism. Even Fenn traps set in unbaited see-through tunnels will catch stoats, when set regularly, but probably at a lower rate than unbaited traps set in similar tunnels (King 1983).

The trial illustrated some other points of difference between the two types of traps.

(1) It is commonly assumed that neophobic reactions by animals to new devices placed in familiar territory mean that catches will be few at first. The Dominus traps were placed new in the field, whereas the Fenn traps had been in place for more than 5 years.

(2) In winter, traps with cold metal treadles may record low catch rates (M. Bygate pers. comm.). The Dominus trap uses a plastic treadle.

(3) On very hot days, the plastic version of the Dominus trap body showed some warping in direct sunlight. Addition of another bolt at the entrance of the trap resolved this issue. Where the plastic trap was used in the bush there were no issues with warping.

(4) Routine checking of Fenn traps requires lifting the tunnel or squinting through one end, whereas Dominus traps can be checked from outside by observing the position of a knot in the setting cord.

(5) Clearing of dead animals from the Dominus required the operator only to pull on the cord and shake the carcass free without handling it. The trap treadle was the only item that needed cleaning, and that could be done without removing it from the trap.

(6) Because the Dominus is self-contained and does not require an additional cover, it was easier to install in the field than are conventional traps with separate covers.

CONCLUSIONS

The main conclusion from this research is that a range of design criteria, including cost effectiveness, ethical considerations, and particularly the ecological and behavioural characters of the target animal, should be established by trap designers before starting work. A preliminary review of the literature, and discussions with scientists and managers quickly identified the importance of tunnels, and the ecological characteristics and behaviour of stoats in designing effective traps. These ecological insights, combined with a commitment to targeting new ethical considerations and manageability, led to design of the Dominus.

Overall then, the kill effectiveness, the small size and portability of the Dominus trap make it a cost-effective and humane alternative to conventional Fenn traps and to other new traps such as the DOC200 and 250 (Warburton et al. 2008). The combination of the superior design of these and other new traps with further research could considerably enhance trap performance and animal welfare, and improve pest control operations over a wide scale.

ACKNOWLEDGMENTS

Funding was provided by the Department of Conservation from a special Government allocation (1999–2004) for developing new initiatives in stoat control. We thank Robin Burley and Wayne Beggs of DOC, Nick Poutu of Manaaki-Whenua Landcare Research, Kim Stubury of Target Pests and David Hunter of Excel for their assistance with the fieldwork, and Cheree and Frances Helps for permitting access to their property and for their enthusiasm for the protection of our native species. We also thank the reviewers and Carolyn King for her helpful comments on drafts of this paper.

REFERENCES

Brown KP 2002. Identifying long-term cost-effective approaches to stoat control. Department of Conservation Science Internal Series 137. Department of Conservation, Wellington, New Zealand.

Brown S 2002. The effect of tunnel shape in the design of animal traps. Unpublished MSc thesis, Lincoln University, New Zealand.

Brown JA, Miller CJ 1998. Monitoring stoat (*Mustela erminea*) control operations: power analysis and design. Science for Conservation 96. Department of Conservation, Wellington, New Zealand.

Brown KP, Moller H, Innes J, Alterio N 1996. Calibration of tunnel tracking rates to estimate relative abundance of ship rats (*Rattus rattus*) and mice (*Mus musculus*) in a New Zealand forest. New Zealand Journal of Ecology 20(2): 217–275.

Clapperton BK, McLennan JA, Woolhouse AD 1999. Response of stoats to scent lures in tracking tunnels. New Zealand Journal of Zoology 26: 175–178.

Clapperton BK, Robbins L, Porter RER, Tallentire K 2006. Testing the attractiveness, palatability and longevity of stoat lure and bait formulations. Department of Conservation Research and Development Series 241, Department of Conservation, Wellington, New Zealand.

Cullen R, Moran E, Hughey KFD 2005. Measuring the success and cost effectiveness of New Zealand multiple species projects to conservation of threatened species. Ecological Economics 53: 311–323.

Department of Conservation and Ministry for the Environment 2000. New Zealand's biodiversity strategy. Department of Conservation and Ministry for the Environment Wellington, New Zealand.

Dilks P, Lawrence B 2000. The use of poisoned eggs for the control of stoats. New Zealand Journal of Zoology 27: 173–182.

Dilks P, O'Donnell CFJ, Elliot G, Phillipson S 1996. The effect of bait type, tunnel design, and trap position on stoat control operations for conservation management. New Zealand Journal of Zoology 23: 295–306.

Dilks PJ, Willans M, Pryde M, Fraser I 2003. Large scale stoat control to protect mohua (*Mohoua ochrocephala*) and kaka (*Nestor meridionalis*) in the Eglington Valley, Fiordland. New Zealand Journal of Ecology 27: 1–9.

Fitzgerald G, Fitzgerald N, Wilkenson R 2002. Social acceptability of stoats and stoat control methods—focus group findings. Science for Conservation 207, Department of Conservation, Wellington, New Zealand.

Gillies CA, Dilks PJ 2003. Evaluating the use of tracking tunnels to monitor mustelids as well as rodents. What's happening with stoat research? Department of Conservation 5: 18–19.

Hamilton B 2004. Using colour to increase stoat (*Mustela erminea*) trap catch. Department of Conservation Science Internal Series 187, Department of Conservation, Wellington, New Zealand.

Horton P, Byron A, Thomson C, Gleeson D, Howitt R, Karl B, Borkin K 2005. Hair tubes: an effective means of detecting stoats. Proceedings of the 13th Australasian Vertebrate Pest Conference, Te Papa, Wellington, 2–6 May 2005.

Innes JG, Skipworth JP 1983. Home ranges of ship rats in a small New Zealand forest as revealed by trapping and tracking. New Zealand Journal of Zoology 10: 99–110.

Jones C, Moller H, Hamilton B 2004. A review of potential techniques for identifying individual stoats (*Mustela erminea*) visiting control or monitoring stations. New Zealand Journal of Zoology 31: 193–203.

King CM 1983. The relationship between beech (*Nothofagus* sp.) seedfall and population of mice (*Mus musculus*), and the demographic and dietary response of stoats (*Mustela erminea*), in three New Zealand Forests. Journal of Animal Ecology 52: 414–466.

King CM 1984. Immigrant killers. Introduced predators and the conservation of birds in New Zealand. Auckland, Oxford University Press.

King CM, Edgar RL 1977. Techniques for trapping and tracking stoats (*Mustela erminea*): a review and a new system. New Zealand Journal of Zoology 4: 193–212.

King CM, O'Donnell CFJ, Phillipson SM 1994. Monitoring and control of mustelids on conservation lands. Part 2: Field and workshop guide. Department of Conservation Technical Series 4. Department of Conservation, Wellington, New Zealand.

Montague TL 2002. Rabbit meat and rodent—scented lures as attractants for stoats (*Mustela erminea*). Department of Conservation Science Internal Series 45. Department of Conservation, Wellington, New Zealand.

Murphy E, Dowding JE 1995. Ecology of the stoat in *Nothofagus* forest: home range, habitat use and diet at different stages of the beach mast cycle. New Zealand Journal of Ecology 23: 97–109.

NZ 245911. Registered patent. New Zealand Patent Office, Wellington, New Zealand.

NZ 510417. Registered patent. New Zealand Patent Office, Wellington, New Zealand.

Pryde M, Lettink M, O'Donnell CFJ 2006. Survivorship in two populations of long-tailed bats (*Chalinolobus tuberculatus*) in New Zealand. New Zealand Journal of Zoology 33: 85–95.

Towns D, Broome K 2003. From small Maria to massive Campbell: forty years of rat eradication from New Zealand islands. New Zealand Journal of Zoology 30: 377–398.

Warburton B, Poutu N, Peters D, Waddington P 2008. Traps for killing stoats (*Mustela erminea*): improving welfare performance. Animal Welfare 17: 111–116.

Wilson KJ 2004. Flight of the huia, Christchurch, New Zealand, Canterbury University Press.

Appendix B

Target species **NAWAC Guidelines**

Feral cat

Trap model	
Belise SuperX in wooden tunnel	Pass
BMI 160 in wooden tunnel	Fail
Conibear 220 in wooden tunnel	Fail
Set n Forget	Fail
Steve Allan set at top of leaning board	Pass
Timms	Pass
Steve Allan (two springs) set in a Philproof Fenn trap tunnel	Pass

Ferret

Trap model	
Belise SuperX	Fail
Conibear 120	Fail
DOC 250	Pass
Holden Multikill	Fail
KBL tunnel	Fail
Possum Master	Fail
S&F	Fail
Set n Forget	Fail
Timms	Fail
Tunnel trap	Fail
Warrior	Fail

Hedgehog

Trap model	
DOC 150	Pass
DOC 200	Pass
DOC 250	Pass

Norway Rat

Trap model	
DOC 150	Pass
DOC 200	Pass
DOC 250	Pass
Nooski	Pass

Possum

Trap model	
Possum Master	Fail
Sentinel	Pass
Set n Forget	Pass
Steve Allan	Fail
Timms	Fail
Warrior	Pass

Ship Rat

Trap model	
DOC 250	Pass

Stoat

Trap model	
DOC 150	Pass
DOC 200	Pass
DOC 250	Pass
Fenn Mk4	Fail
Fenn Mk6	Fail
Victor snap-back professional	Fail

Updated May 2008 Retrieved on March 2009 from http://www.landcareresearch.co.nz/research/pestcontrol/trapdesign/welfare_performance.asp

Appendix C

Stoat Trap Field Trial – Thumper, DoC 180 and Fenn traps

Staff survey of trap performance, ease-of-use and general acceptability

Thanks for undertaking the fieldwork for this trial. Please take a minute to comment on how the traps performed in the field by completing this survey.

Date: / / Site: Name:

Comparison Thumper / DoC180 / Fenn

Trial (circle) Paired Alternate

There is a separate response space for each trap you trialled for the majority of questions. This will help to measurably compare the traps trialled. You can comment after questions where necessary, and also at the end of the survey.

1	2	3	4	5	N/A
Very good No problems	Good Easy	Average OK	Poor Difficult	Disappointing Nightmare	

Trap transporting

How would you describe transporting – (including trap covers/boxes)

Thumpers to site? 1 2 3 4 5 N/A
DoC180's to site? 1 2 3 4 5 N/A
Fenns to site? 1 2 3 4 5 N/A

To what degree were traps damaged during vehicle/foot travel? How did they handle it?

Thumper 1 2 3 4 5
DoC180 1 2 3 4 5
Fenn 1 2 3 4 5

Briefly describe cause/problem and actions that may help future transporting?

Thumper -
DoC180 -
Fenn-

Trap set-up/placement

How easy was trap set-up at each site? (including any trap covers/boxes)

Thumper 1 2 3 4 5
DoC180 1 2 3 4 5
Fenn 1 2 3 4 5

How easy was it to find the trap again following set-up?

Thumper 1 2 3 4 5
DoC180 1 2 3 4 5
Fenn 1 2 3 4 5

Trap adjustment

Describe how well the trigger mechanisms functioned on the *first* set (how much, if any, trigger/trap adjusting was required on set-up?)

Thumper 1 2 3 4 5

DoC180 1 2 3 4 5
Fenn 1 2 3 4 5

Describe requirement to service traps (trigger etc) *during* trial?
Thumper 1 2 3 4 5
DoC180 1 2 3 4 5
Fenn 1 2 3 4 5

Trap setting/checking
How easy was it to check and rebait/reset the traps during the trial?
Thumper 1 2 3 4 5
DoC180 1 2 3 4 5
Fenn 1 2 3 4 5

How easy was it to remove animals caught in traps? Thumper 1 2 3 4 5
DoC180 1 2 3 4 5
Fenn 1 2 3 4 5
Describe degree of trap cleaning necessary, if any? Thumper 1 2 3 4 5
DoC180 1 2 3 4 5
Fenn 1 2 3 4 5
Notes -

Humanness/non-target kills
How would you describe the overall humanness of kills in the traps you cleared?

Thumper 1 2 3 4 5
DoC180 1 2 3 4 5
Fenn 1 2 3 4 5

Did the trap catch any non-target animals? Thumper NO YES detail-
DoC180 NO YES detail-
Fenn NO YES detail-

Did you have the non-target bar in place on the Thumpers? NO YES

Trap damage/interference
Did you have to pull any traps out of service following normal wear and tear (indication of poorly manufactured/designed traps) Thumper NO YES detail-
DoC180 NO YES detail-
Fenn NO YES detail-

Did any traps get damaged by falling debris? Thumper NO YES detail-
DoC180 NO YES detail-
Fenn NO YES detail-

To what degree could the trap/s be repaired following the incident?
Thumper 1 2 3 4 5 DoC180 1 2 3 4 5
Fenn 1 2 3 4 5

To what extent were the traps interfered with by animals in the forest?
Thumper 1 2 3 4 5 DoC180 1 2 3 4 5
Fenn 1 2 3 4 5

Do you feel this level of interference upset trap catchability of target animals?
Comment-

Overall satisfaction

Summarise your general satisfaction with the trap

Thumper	1	2	3	4	5
DoC180	1	2	3	4	5
Fenn	1	2	3	4	5

General comments

Detail any other points you think might benefit effective future field use of these traps;

- positives/negatives
- possible refinements
- durability
- ease-of-use

Thank you very much for participating in the trial. Your input will be used to further advance our battle against these voracious little predators.

If you have any queries feel free to contact us.
Elaine Murphy and Fraser Maddigan, Science and Research Unit, Christchurch.

Appendix D

Trauma scale developed by ISO Technical Committee 191

Pathological observation Score

Mild trauma

1) Claw loss 2 points

2) Oedematous swelling or haemorrhage 5 points

3) Minor cutaneous laceration 5 points[1]

4) Minor subcutaneous soft tissue maceration or erosion 10 points

5) Major cutaneous laceration, except on footpads or tongue 10 points

6) Minor periosteal abrasion 10 points

Moderate trauma

7) Severance of minor tendon or ligament 25 points

8) Amputation of 1 digit 25 points

9) Permanent tooth fracture exposing pulp cavity 30 points

10) Major subcutaneous soft tissue laceration or erosion 30 points

11) Major laceration on footpads or tongues 30 points

12) Severe joint haemorrhage 30 points

13) Joint luxation at or below the carpus or tarsus 30 points

14) Major periosteal abrasion 30 points

15) Simple rib fracture 30 points

16) Eye lacerations 30 points

17) Minor skeletal degeneration 30 points

Moderately severe trauma

18) Simple fracture at or below the carpus or tarsus 50 points

19) Compression fracture 50 points

20) Comminuted rib fracture 50 points

21) Amputation of two digits 50 points

22) Major skeletal degeneration 50 points

23) Limb ischaemia 50 points

Severe trauma

24) Amputation of three or more digits 100 points

25) Any fracture or joint luxation on limb above the carpus or tarsus 100 points

26) Any amputation above the digits 100 points

27) Spinal cord injury 100 points

28) Severe internal organ damage (internal bleeding) 100 points

29) Compound or comminuted fracture at or below the carpus or tarsus 100 points

30) Severance of a major tendon or ligament 100 points

31) Compound or rib fractures 100 points

32) Ocular injury resulting in blindness of an eye 100 points

33) Myocardial degeneration 100 points

34) Death 100 points