Biosecurity at the Extreme: Pathways and Vectors between New Zealand and Scott Base, Antarctica

By

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Abstract

Biosecurity is one of the main mechanisms used to protect and mitigate the introduction of non-indigenous species. Effective biosecurity requires a knowledge and understanding of pathways and vectors along which invasion can occur. This study contributes to our knowledge and understanding of possible biosecurity risk factors in the Antarctic by identifying potential vectors for invasive species in the pathway between New Zealand and the Antarctic. The Antarctic has important indigenous terrestrial and marine, plant and animal species, all of which contribute to the food chain in Antarctica and the Southern Ocean.

This study seeks to contribute some baseline data about pathways and vectors between the two regions and the implications for the biosecurity of both. An assessment of some of the risks associated with human activities within the Antarctic region, including the traffic of people and goods to and from the area, are the focus of this thesis. Current biosecurity practices with regard to personnel, shipping containers, and fresh produce are examined and where appropriate, recommendations to alleviate any detected risks are made.

The results of the research indicate a significant volume of seed and plant material being unintentionally transported to Antarctica. The most striking finding was the presence of seeds in new clothes, which have previously been assumed not to be vectors. The presence of seeds in soil samples in Antarctica suggests that seeds have probably already been transported to Antarctica. Presently the climate in Scott Base seems to prevent non-indigenous species from becoming established. However, with the increases in temperature being experienced in Antarctica, this may not always be the case, therefore greater attention to biosecurity legislation and its implementation is required.

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And for all those who asked, there are no trees in Antarctica.

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AAD	Australian Antarctic Division
AQIS	Australian Quarantine Inspection Services
ASPA	Antarctic Specially Protected Areas
ATCM	Antarctic Treaty Consultative Meetings
ATS	Antarctic Treaty System
CCAMLR	Convention on the Conservation of Antarctic Marine Living Resources
CEP	Committee on Environmental Protection
COMNAP	Council of Managers of National Antarctic Programmes
EIA	Environmental Impact Assessments
EMS	Environmental Management System
EPBC Act	Environment Protection and Biodiversity Conservation Act 1999
IAATO	International Association of Antarctic Tourist Operators
IUCN	International Union for the Conservation of Nature
M4	Macquarie Wharf, Tasmania
MARPOL	Marine Pollution Convention
MFAT	Ministry of Foreign Affairs and Trade
MOU	Memorandum of Understanding
NZAP	New Zealand Antarctic Programme
RNZAF	Royal New Zealand Air Force
SCAR	Scientific Committee on Antarctic Research
USAF	United States Air Force
USAP	United States Antarctic Programme
USSR	Union of Soviet Socialist Republics

1. Background

1.1. Antarctica

The history of Antarctic's exploration shows that humans have had an impact on the region since 1820 (Crossley, 1995). From that early date explorers continued this tradition, living temporarily on the ice as they pushed the boundaries of discovery, until about 1900. Thereafter there has been an ever increasing interest in establishing permanent bases on the ice to enable long-term and ongoing occupation by scientific programmes, and more recently visits by tourists and adventurers (Frenot *et al*., 2005). The establishment of permanent bases commenced in 1903, first by Argentina, followed by a number of other countries including New Zealand, which opened a base in 1957-58 (McGonigal & Woodworth, 2002). This increased interest in the Antarctic led to the drawing up of the Antarctic Treaty in 1959 and associated protocols which aimed to protect the Antarctic continent and to ensure that only scientific and peaceful activities are carried out there.

Antarctica possesses a unique climate and environment. It has important indigenous terrestrial and marine, plant and animal species, all of which contribute to the food chain in Antarctica and the Southern Ocean. This food chain is essential for the survival of many species and for maintaining the equilibrium of the ecosystem in the region. The ecosystem is in delicate balance and because of the relationship of the land and the sea and the ice mass it is considered that any detrimental effects on any one component will adversely effect the others (Kimball, 1993). In order to protect the fragile environment of Antarctica, it is critical that non-indigenous species do not become established.

Biosecurity is one of the main mechanisms used to protect and mitigate the introduction of non-indigenous species. Effective biosecurity requires a knowledge and understanding of pathways and vectors along which invasion can take place in any particular environment. Whilst internationally, scientific research has taken account of the potential of pathways for the transmission of invasive organisms, the Antarctic region has not come under scrutiny to the same extent as other locations. With the escalating number of visitors to the region this lack of research makes an examination of the environmental threats and relevant risk management strategies urgent to protect the Antarctic from destruction and pollution (Frenot *et al.*, 2005). Of particular note is the level of traffic between New Zealand and the Antarctic in spite of its being separated by the Southern Ocean.

To date, the question of how important the pathways might be seems to have evaded detection, partly perhaps because of the distance separating the two areas, New Zealand and Antarctica. This study seeks to contribute some baseline data about pathways and vectors between the two regions and the implications for the biosecurity of both. An assessment of some of the risks associated with human activities within the Antarctic region, including the traffic of people and goods to and from the area, are the focus of this study. Recommendations to alleviate any detected risks will be made.

1.2. Biosecurity

Biosecurity is important to New Zealand as we are primarily an agricultural economy. As an isolated series of islands we are currently free from many serious pests and diseases found elsewhere in the world (Ochoa-Corona *et al.*, 2005). Responsibility for biosecurity rests with several government organisations in New Zealand, including the Ministry of Agriculture and Forestry (MAF). Ongoing research projects in government departments and universities continually seek to enhance protection of the country's agriculture, horticulture and natural habitats. However, to date no research into biosecurity issues as they relate to New Zealand's Antarctic base in Christchurch and to Scott Base or the Ross Sea Region, Antarctica has been undertaken.

New Zealand's definition of biosecurity has evolved in the past two decades due to increased understanding and knowledge of the implications of border control. Early definitions of biosecurity (Penman, 1998) referred to the management of risk arising from pests, weeds and diseases, both exotic and endemic. The current definition used by the New Zealand Government in the Biosecurity Strategy (Young, 2003) specifies the following:

> *"Biosecurity is the exclusion, eradication or effective management of risks posed by pests and diseases to the economy, environment and human health"*.

This most recent definition focuses on the cost-effectiveness of protecting natural resource from organisms capable of causing damage. It relates to both the protection of people and natural resources, including biodiversity, from detrimental organisms (Young, 2003). It is this definition of biosecurity that informs this study.

1.3. Vectors and pathways

Vectors and pathways are the means by which invasive species move from one area to another. The form of these vectors and pathways are dependent upon the nature of the locations and the objects moving between them (Frenot *et al.*, 2005). In this subsection, I will consider the movement of non-indigenous species using different vectors and pathways globally and then focus on Antarctica, on those pathways suspected of being used by non-indigenous species to travel between New Zealand and Scott Base in Antarctica.

Vectors are defined by Ruiz and Carlton (2003) as being the transfer mechanism by which a species moves from one location to another (the pathway). Pathways are defined by Mack (2003) as being a route, with a starting point and as having one or more destinations.

1.3.1. Global

Globally there are a multitude of vectors and pathways available to invasive species. These differ between areas due to the presence of land links, the extent of shipping, the types of animals moving through, and the number of people transiting.

Land links are common throughout the world, linking nations or multiple nations together. Water is a natural barrier for many species and acts to restrict the movement of species that can only travel short distances under their own power. For example the clover root weevil was contained to the North Island of New Zealand since its discovery there in 1996 and has only recently been found in the South Island. It was thought that the Cook Strait created a barrier for a time. There is speculation that the weevil may have crossed the Cook Strait by clinging onto vehicles or freight transported on the ferries between the two islands (Biosecurity New Zealand, 2006a).

Although water may act as a barrier in some instances, it is also the case that the movement of both sea and river water can effectively transport non-indigenous species to new sites. Research carried out in the Palmer River mouth in New England, USA by Minchinton (2006) looked at the potential for dead plant material or mats to act as vectors for the dispersal of plants along the river bank. In an area of 2.5km along the river bank effected by tidal activity, 30 species of plants and two of algae were found to be associated with the movement of dead plant material. A further 24 seeds germinated in glasshouse conditions. Mats travelled from 1.1km- 2.6km per hour which indicates there was a potential dispersal distance of 6.5km to 15.9km per tide. The authors noted that dead plant material was a major player in the dispersal of plants in coastal marshes and estuaries (Minchinton, 2006).

Birds have been very successful in the movement of pests and diseases throughout the world. Kipp *et al.* (2006) investigated the spread of the disease *Borrelia burgdorferi* using ticks as a vector on birds which carried the infected ticks. Kipp's study concluded that the movement of disease by birds was an effective vector. Birds such as seagulls have been found to be effective in the spread of invasive species by faecal material, including passing infected faeces into the sea (Vanpatten *et al.*, 2004).

Marine organisms pose a major threat to coastal areas worldwide. Ballast water is a well known vector for the movement of non-indigenous species (Hayes & Sliwa, 2003). Research on intracoastal shipping discharge of ballast water found domestic ships were capable of transferring large volumes of non-indigenous and native nuisance pests (Coutts & Taylor, 2004; Lavoie *et al.*, 1999). The spread of unwanted organisms rapidly caused major problems within the newly invaded environments. For example, the invasion of zebra mussels *Dreissena polymorpha* into 18 states in the United States and two provinces of Canada occurred within seven years of their first introduction. The vectors were ships and recreational boats that moved throughout the waterways. Although it was found that ducks were capable of transporting the mussels, it was the overland movement by recreational boats that was responsible for the spread of the large numbers of mussels (Johnson & Padilla, 1996).

Recent experience in New Zealand has linked the spread of *Didymosphenia geminata* between water ways to the movement of recreational boaters and the use of fishing equipment infected with spores (Biosecurity New Zealand, 2006b). The spread of lake-weed in the Rotorua lakes in New Zealand has been attributed to recreational boat owners. The Bay of Plenty authority is seeking to contain the spread of *Ceratophyllum demersum* by alerting boat owners to the transmission of the weed on propellers and trailers (Environment Bay of Plenty, Press Release, 22 August 2005).

People are also recognised vectors in the movement of non-indigenous species. This was particularly evident during the foot and mouth outbreak in the United Kingdom. Strict controls were enforced to restrict people, vehicles and animals moving throughout the country. I saw people being required to disinfect vehicle wheels and shoes when disembarking from the ferry from Hollyhead in Wales when in transit to the Irish port of Dun Laoghaire. However, such efforts are hampered when people do not understand the implications of the spread of disease and fail to comply with safety precautions. Cooperation and education is the key to ensuring success in such instances (Scudamore & Harris, 2002).

New Zealand is a popular tourist destination. For example during March 2006, 227,000 short term visitors came to New Zealand; there were 2.4 million visitors to the year ending March 2006[1]. This large number of arrivals has the potential to carry a significant volume of unwanted organisms into the country. To address this risk all baggage and mail entering New Zealand is scanned using x-ray machines to locate any plant material, food, animals or seeds. Quarantine officers using sniffer dogs carry out inspections and searches of passengers and cargo coming into New Zealand's airports, ports and mail centres. The New Zealand Ministry of Agriculture and Forestry's Quarantine Service seized 120,882 items in the 2000-2001 year. Detection of seeds, meat, poultry and bee products increased significantly since 1995 and reached the highest levels ever in New Zealand in 2000-01. This increase is thought to be in part due to greater vigilance at the borders and in part due to an escalating

[1] http://www.stats.govt.nz/analytical-reports/monitoring-progress/envmt-ecosystem-resilience/biosecurity.htm Statistics New Zealand accessed on 10/05/06

amount of material being brought into New Zealand. Consequently there is rising concern in the biosecurity community that there is a greater risk to biosecurity in New Zealand since 1995[2]. Increasing volumes of traffic correlates to increasing risk.

1.3.2. Antarctic

This study focuses on the pathway from Christchurch (New Zealand) to Antarctica. This pathway does not contain any land-links. The potential vectors for the introduction of undesirable species and diseases to Antarctica are people and cargo, ships and ballast water. Ballast water has received the most attention from researchers (Lewis, *et al.*, 2003; Lewis *et al.*, 2004; Lewis *et al.*, 2005; Tavares & De Melo, 2004). These researchers have noted the dispersal of exotic species in marine environments, biofouling adhering to ships and floating anthropogenic debris all of which are of concern. The continued increase in the number of ships travelling to Antarctica for tourism, commercial fishing and oceanographic research activities (Tavares & De Melo, 2004) suggests that ballast water may be a major vector.

People and cargo represent the two other major vectors for the possible introduction of animals, vegetation and mineral matter into Antarctica (Frenot *et al.*, 2005). With the exception of one study by the Australian Antarctic Programme (AAD) on the introduction of non-indigenous species, little research has been carried out in this field[3].

1.3.3. Scott Base and New Zealand

The pathway between New Zealand and Scott Base is quite easy to define. It is the route from Antarctica New Zealand's base in Christchurch to Scott Base, on Ross Island, either by air (via Christchurch International Airport), or by sea (via Lyttleton and McMurdo Station). The vectors, however, associated with this pathway are more varied. Both unintentional and intentional transmission of undesirable species can

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[2] www.maf.co.nz accessed on 10/05/06

[3] www.aad.gov.au accessed on 02/03/06

result from this pathway. For air travel this comprises the aircraft including the wheels and/or skis. People can be vectors, including their clothing, carry-on luggage and any species of plants or animals they may be intentionally taking with them. The aircraft's cargo is also a potential vector, and includes 'freshies', scientific equipment and personal supplies for longer term residents at Scott Base. The shipping route likewise introduces possible vectors including shipping containers, vehicles, people, instruments, and personal belongings.

The first flights for the Antarctic summer season (October – February) begins with 'winfly' that occurs at first light in August (Table 1.1). Winfly consists of four return flights from Christchurch to McMurdo and are carried out by the United States Air Force (USAF). USAF flights between New Zealand and Antarctica are carried out using USAF C17 Globemaster aircraft and in the 2005/06 season totalled 81 return flights. The final flight of the season by USAF is on the 26^{th} February, weather permitting. In addition the Royal New Zealand Air Force (RNZAF) carried out 6 return flights between the 15^{th} November and the 17^{th} December using C130 Hercules equipped with wheel or ski landing devices. The flights are made up of a combination of participants from the USAP, Italian Antarctic Programme and the New Zealand Antarctic Programme.

Table 1.1 Shows the operating dates, the aircraft and country of origin, the number of return flights, and flight times to Ross Island, Antarctica during the 2005/06 season[4].

Date	**Aircraft**	**No. of return flights**	**Average Flight Time**
Winfly (August)	US Air Force C17 Globemaster	4	5-6 hours
1 October – 14 November	US Air Force C141 Starlifter and C17 Globemaster	47	5-6 hours
15 November – 17 December	RNZAF C130 Hercules (wheeled)	12	7-8 hours
18 December – 3 January	US Air National Guard LC139 Hercules (ski equipped)	3	8-10 hours
4 January – 26 February	US Air Force C141 Starlifter and C17 Globemaster	30	5-6 hours
Total number of return flights		**96**	

Table 1.2 Number of return flights that each Antarctic Programme puts into the logistical pool[5].

Antarctic Programme	**Number of return flights**
USAP	81
Antarctica New Zealand	12
Italian Antarctic Programme	3
Total	**96**

The total number of flights during the 2005/06 season to Ross Island was 96 return flights (Table 1.2). These flights transported 6,246 passengers from the USAP, Italian Antarctic Programme and New Zealand Antarctic Programme. The check in bag weight for these passengers was 186,664 kg and the passenger weight, including carry-on luggage and wearing the Extreme Cold Weather clothing (approximately 11.5 kg per person), was 648,892 kg (Table 1.3). Other cargo and tie down equipment that was airlifted to Antarctica had a total weight of 1,219,093 kg and 157,696 kg respectively. In addition there was US Mail (77,915 kg) and Freshies which totalled

[4] Table reproduced from www.antarcticanz.govt.nz accessed on 01/06/06

[5] Data courtesy of Antarctica New Zealand 25/05/06

94,789 kg. The total payload for all these different aspects is 2,394,792 kg. This is a substantial volume and represents vectors by which a significant threat could enter the Antarctic environment potentially causing major problems.

Table 1.3 weights of cargo (kg), passengers and other freight that was transported by air to Antarctica in the 2005/06 season[6].

Passengers and cargo description	Total weights (kg)
Passenger number	6,246
Passenger weight	648,892
Bag weight (Check in)	186,664
US Mail	77,915
Freshies	94,789
Tie down equipment (TDE)	157,696
Other cargo	1,219,093
Total cargo weight (less passenger weight)	1,745,900
Total payload (weight)	**2,394,792**

Scott Base (NZAP) and McMurdo (USAP) are also supplied by ship. These ships operated between Port Hueneme in the United States, Lyttleton Port in Christchurch, New Zealand and McMurdo, Antarctica. In the 2005/06 season the re-supply vessel discharged a total cargo of 5,455,295 kg. This included 711 containers and 18 pieces of breakbulk cargo. Breakbulk cargo is un-containerised equipment. For a breakdown of the cargo shipped in the 2005/06 season see Table 1.4.

[6] Data courtesy of Antarctica New Zealand 25/05/06

Table 1.4 Shows the resupply vessel operations and the on-load and off-load of TEUs at Hueneme, USA, Lyttleton, New Zealand, and McMurdo Antarctica during the 2006 season. TEU is a standard 20 foot container or equivalent. A forty foot container is two TEUs[7].

Name of Port	On-load TEUs	Off-load TEUs
Hueneme	772	594
Lyttleton (1st trip)	95	8
McMurdo	630	859
Lyttleton (2nd trip)	17	53
Total	**1514**	**1514**

Table 1.5 is a breakdown of the type of containers (TEUs) that were discharged at McMurdo during the 2005/06 season. The total number of passengers and volume of cargo making its way to Antarctica each summer season is sizeable.

Table 1.5 The resupply vessel's total cargo discharge at McMurdo ice wharf during the 2005/06 season[8].

Type of container (TEUs)	Number of containers (TEUs)	Weight (kg)
20' Dry	438	
20' Reefer	80	
20' Flatrack	43	
40' Dry	12	
40' Flatrack	135	
40' Reefer	1	
Miscellaneous Units	2	
Total (containers)	**711**	5,205,868
Breakbulk 18 pieces	**18**	249,427
Total Discharged		5,455,295

1.4. International collaboration

There is significant international logistical collaboration which ensures the success of the scientific programmes based in Antarctica. The New Zealand Antarctic Programme (NZAP) is involved in a logistical pool incorporating New Zealand, Italy

[7] Data courtesy of Antarctica New Zealand 07/06/06

[8] Data courtesy of Antarctica New Zealand 07/06/06

and the United States of America. For the purposes of this thesis, only the activities of the NZAP will be studied.

The International Antarctic Centre in Christchurch, New Zealand, is the home base of the NZAP and is operated by Antarctica New Zealand. The United States Antarctic Programme (USAP) and the Italian Antarctic Science Programme are also both based at the International Antarctic Centre in Christchurch. These three countries share resources including transport planes, ships, the ice wharf at Scott Base, air landing strips in Antarctica and storage space in Christchurch, New Zealand. A large number of scientists and staff, as well as cargo and equipment, arrive in Christchurch from the United States, Italy and elsewhere en route for Antarctica. Responsibilities are shared between these participating nations. For example, typically New Zealand’s role includes medical evacuations from Antarctic, particularly during winter. New Zealand also pays all landing fees at Christchurch International Airport. In exchange for this, The USAP maintains the runway in Antarctica. There is also a pooling of space on aircraft between these three Antarctic Programmes. This network of co-operation and collaboration provides a strong support network for each of these countries but also poses possible risk of contamination between Antarctic bases, Christchurch and other countries.

1.5. Tourism in the Antarctic

Improvement in transportation has meant it is now easier and faster to move around the globe. The impact of this has been felt within Antarctica in reduced air travel time from destinations to Antarctica and the use of snow-mobiles and all-terrain vehicles (such as Hagglunds) which make travel within Antarctica easier. These changes have increased the threat to the Antarctic environment by the biosecurity risks associated with the use of planes, ships and equipment in this unique environment. The break up of the USSR in 1991 resulted in an increase in the number of ice-strengthened vessels and ice-breakers available for charter and thus for eco-tourism to the Antarctic. This meant an increase in tourist operators, and therefore passengers, travelling to the Antarctic. Humans present a risk to the delicate Antarctic environment by introducing and translocating micro-organisms (Blackburn & Duncan, 2001) and increasing numbers of visitors to concentrated areas of wildlife, particularly penguin rookeries, have heightened the concern (Blackburn & Duncan, 2001; Kimball, 1993).

These concerns have been met by action on the part of some tourist operators. The number of cruise visitors is reported to have increased from 3000 in the 1988-89 summer to 6500 in 1992-93. A category of tourist known as 'adventurer travellers' numbered 75 in the 1990-91 season and is though to have grown significantly since that time (Kimball, 1993). The International Association of Antarctica Tourism Operators (IAATO) was founded in 1991 to monitor the movement of tourist ships in the Antarctic. It is a self-regulating organisation with 69 members. IAATO aims to encourage private-sector travel to the Antarctic to be environmentally responsible (International Association of Antarctic Tourist Operators, 1991). Tourism figures released by IAATO highlight the dramatic increase in private-sector visitors between 1992 and 2004, as the sector continues to grow. As shown in Figure 1.1 the number has doubled over this period to nearly 14,000 per season.

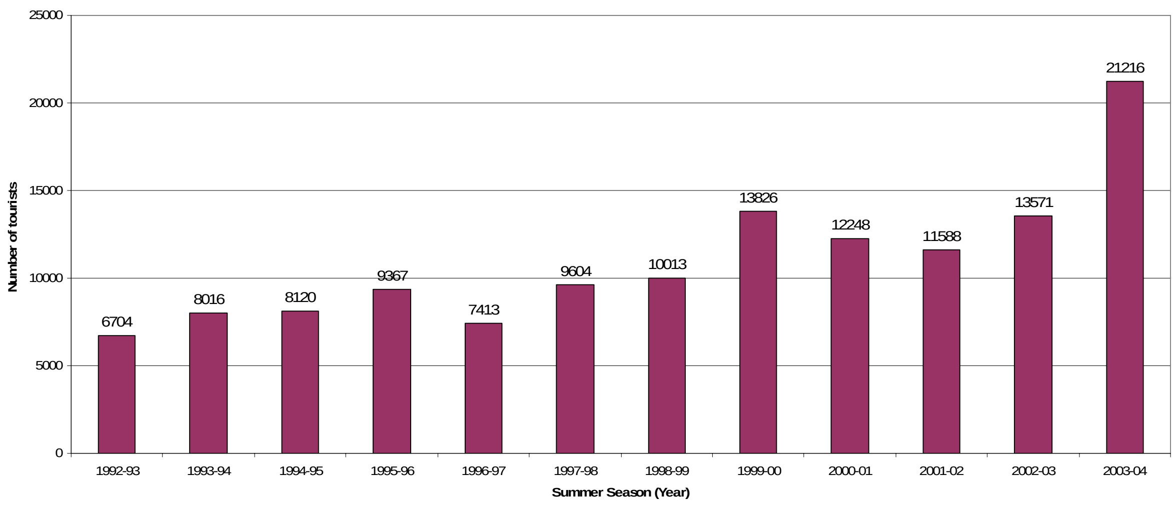

Figure 1.1 Tourist numbers in the Antarctic between 1992 and 2004[9]. Tourist numbers have more than doubled during this period.

[9] www.iaato.org, accessed on 10/5/06

1.5.1. International Association of Antarctic Tourism Operators Guidelines

The International Association of Antarctica Tourism Operators (IAATO) has used its forum to develop guidelines to encourage members to protect the environment they rely on for an income. The most relevant guidelines to biosecurity are those relating to the decontamination of boots and clothing by staff and tourists on privately-owned tourist boats. Many locations in Antarctica are of common interest to both scientists and tourists, including penguin colonies and the huts used by early explorers. However it is not only fauna and historic sites that attract comment about the impact of tourists. It has been suggested that visits by tourists to some scientific bases be discouraged due to the disruption caused to base staff and scientists. Anecdotal evidence suggests that such visits can have a detrimental impact. For example, during one visit several base staff were invited to the tourist ship, subsequently became sick and passed this illness on to the rest of the base.

IAATO argues there is no conclusive evidence that tourists have introduced or transmitted diseases to the Antarctic. However, they recognise there is a potential risk and have produced guidelines to reduce the likelihood of visitors becoming vectors both inter-continentally (to and from Antarctica) and intra-continentally (within Antarctica). Pre-voyage information is supplied to passengers on the cleanliness of boots and clothing, especially for those who have been tramping, camping, backpacking or visited a farm prior to arriving in Antarctica. Passengers are advised to check Velcro, camera tripod feet, pockets for seeds and backpacks for mud, seeds and other vegetation. Prior to landing, passengers are reminded again to clean boots and clothing. Many boats have facilities to assist them. During landings passengers are encouraged to avoid organic material such as guano, seal faeces and placenta to reduce the risk of moving this material around the area. Before re-boarding the Zodiac to be ferried ashore, passengers stand on a plywood board and their boots are scrubbed to remove any debris from the soles. Any items such as clothing or backpacks that have touched the ground are cleaned. The brushes are cleaned before being used at another site to reduce the impact of cross contamination. When passengers return to the ship, boots and clothing are cleaned again at the boot washing station.

Boot washing stations are recommended by IAATO to be located on deck close to the point where passengers re-board the vessel, usually at the head of the gangway. In this position they can also serve those who arrive by helicopters or other landing craft. IAATO suggests the stations are equipped with running water, scrubbing brush, coarse mat and a hose. Water is drained off the ship into the sea, and debris from boots and clothing is collected in a shallow tray. The guidelines suggest that between each landing every effort be made for the clothing and boots to dry out completely, as desiccation is an effective means of controlling some micro-organisms. Finally, passengers should be reminded to check their boots and clothing again before leaving the ship.

While it is a positive move that organisations such as IAATO are taking action and are committed to monitoring the impact of their tourist activities on the environment, a limitation is that the guidelines are voluntary and not legally binding. If a tourist operator is not from a member country of the Antarctic Treaty System, and/or IAATO, limited action can be taken to ensure activities are carried out responsibly on the ice. Many of the operators adhere to the IAATO guidelines in general but there are varying standards of implementation (D. Hasse, pers. comm., 2006).

1.6. Indigenous plant species in the Antarctic

Colobanthus quitensis and *Deschampsia antarctica* are the only two native vascular plant species present in Antarctica. Over the past 30 years both species have been increasing along the West Coast of the Antarctic Peninsula. This is most likely due to regional warming. The increase in air temperature has meant there is an increase in de-glaciated areas on the Antarctic Peninsula and therefore a greater area for native species to thrive (Ruthland & Day, 2001).

A study conducted by Ruthland and Day in (2001) found that *C. quitensis* seeds stored at 3^{o}C for 120 days and greater than 4 years had a germination rate of 6% and 38% respectively. When compared to previous studies reviewed by Ruthland and Day (2001) these germination rates are much higher, which suggests that earlier studies greatly underestimated seed bank densities and germination rates in the Antarctic. It has been established that *C. quitensis* and *D. antarctica* have persistent seed banks in

Antarctica, with dormant seeds. The longevity of the seeds is unknown as species seem to produce few viable seeds during any summer growing season in the Antarctic (Ruthland & Day, 2001).

1.7. Time lag

The impact of a species over time is characterised by time lag. That is to say that the population of a species increases and has more of an impact as time progresses. This is often represented by time lag diagrams as shown in Figure 1.2. This phenomenon is important to an understanding of the properties of invasive species. Low populations of invasive species can exist relatively undetected before a period of rapid growth means they become dominant. An invasive species is often difficult to locate and identify as it can remain undetected for long periods of time before competing with indigenous species and thereby drawing attention to its presence (Clout, 2006).

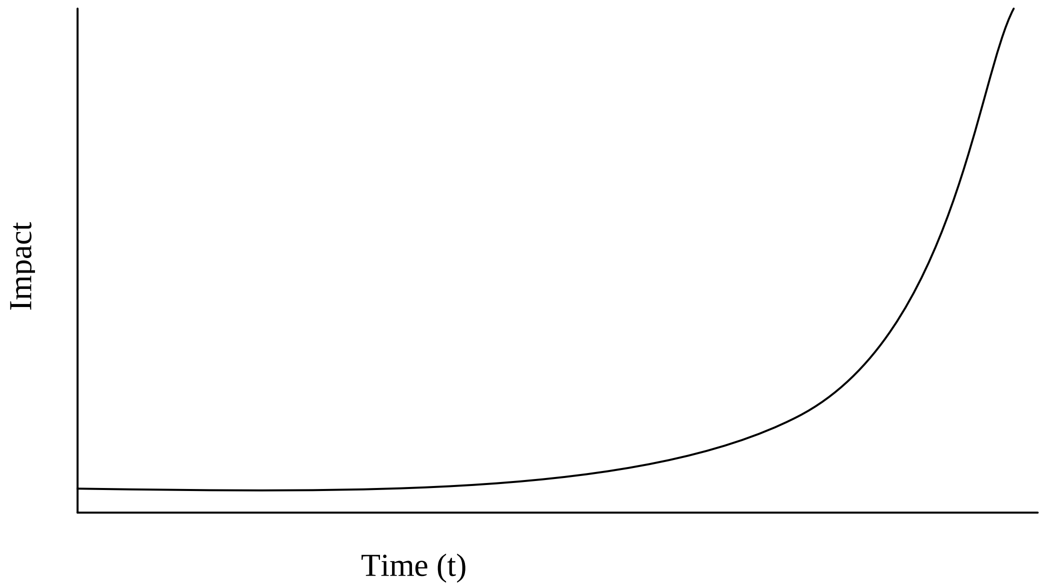

Figure 1.2 An example of a time lag diagram indicating how as time goes by, the impact of the invasive species significantly increases.

The time lag between the naturalisation and the full potential for damage by introduced species means that the management and/or eradication of the potential hazard is a major problem. In New Zealand many species previously unknown in this country, have been found by researchers in gardens and streams (Young, 2003). A lack of understanding of aquatic ecosystems and the lack of baseline data means it is difficult to classify a species as non-indigenous.

Given that in New Zealand there are problems identifying and controlling non-indigenous pests, we face a much bigger challenge in the Antarctic where even less is known about the aquatic and terrestrial environment. Time lag is important. Although there are no visible signs of non-indigenous vascular species growing in the Antarctic this does not prove their absence. It may rather suggest that a lack of visible signs is evidence of species which are in the early stages of time lag. On the other hand, it could be evidence there is actually nothing undesirable growing. If so, it is desirable for this situation to be maintained. Vigilance is necessary.

1.7.1. Vertebrates

Although vertebrates are outside the scope of this thesis it is noted that they do pose a high level of threat to the Antarctic (Frenot et al., 2005; Hanel & Chown, 1998). Invasive species (excluding diseases) are the third highest threat to ecosystems, the first two being habitat loss and over-exploitation. Non-indigenous species pose the fifth biggest threat to biodiversity of the marine environment. Islands and other isolated ecosystems are especially threatened by invasive species due to the secluded nature of their environment[10]. Antarctica is one such environment. Research detailing with rodent infestations and other pests includes Hanel & Chown (1998), Le Roux *et al.* (2002) and Smith, *et al.* (2002).

1.8. Aims

This study contributes to our knowledge and understanding of possible biosecurity risk factors in the Antarctic by identifying potential vectors for invasive species in the pathway between New Zealand and the Antarctic. This study will establish the level

[10] www.iucn.org accessed on 10/04/06

of risk to this species-poor environment and suggest procedures to reduce the introduction and spread of unwanted plant species.

The identification of the threats to the Antarctic environment is necessary to protect the region's naturally occurring plant and animal life. To date no systematic evaluation has been conducted of the current biosecurity policies and practices used by organisations involved in the Ross Sea Region, and no data is available on the transport operations between New Zealand and Antarctica. The aim of this study is to address this gap in the literature. The research will identify and examine the major pathways for invasive species to Antarctica. An examination of the procedures for people, clothing, cargo and containers moving from Antarctic New Zealand Base in Christchurch, New Zealand to the Ross Sea Region of Antarctica will establish if any of these are viable vectors of risk.

This study aims to investigate the following research questions:

1. What are the biosecurity risks for introducing non-indigenous species to the Ross Sea Region and what vectors exist e.g. cargo, people, ships?

2. Are the current biosecurity practices adequate?

   i. What is the legal status of biosecurity in Antarctica?
   ii. Can seeds be found on containers and/or in equipment?
   iii. Can seeds be found in clothing destined for the Antarctic?
   iv. Are seeds found in the soil of Scott Base?
   v. What practices are in place to prevent the introduction of non-indigenous species?

1.8.1. Location of study

This study was confined to the activities of Antarctica New Zealand to allow the study to focus on detailed research in one area. Antarctica New Zealand operates bases in New Zealand (Christchurch) Figure 1.3, and in Antarctica (Scott Base) Figure 1.7. Antarctica New Zealand's New Zealand base is located in Harewood, Christchurch, New Zealand, on the fringes of Christchurch International Airport, as illustrated in, Figure 1.4 and Figure 1.5.

Figure 1.3 A map of New Zealand showing the location of Christchurch, New Zealand, on the east coast of in the South Island[11].

Some of the cargo bound for Scott Base is transported by sea rather than by air. The ships taking this cargo dock at Lyttleton Port. This cargo is transported by truck from Antarctica New Zealand (Harewood) to Lyttleton Port whose relative location can be seen in Figure 1.4.

[11] www.aa.co.nz accessed on 07/05/06

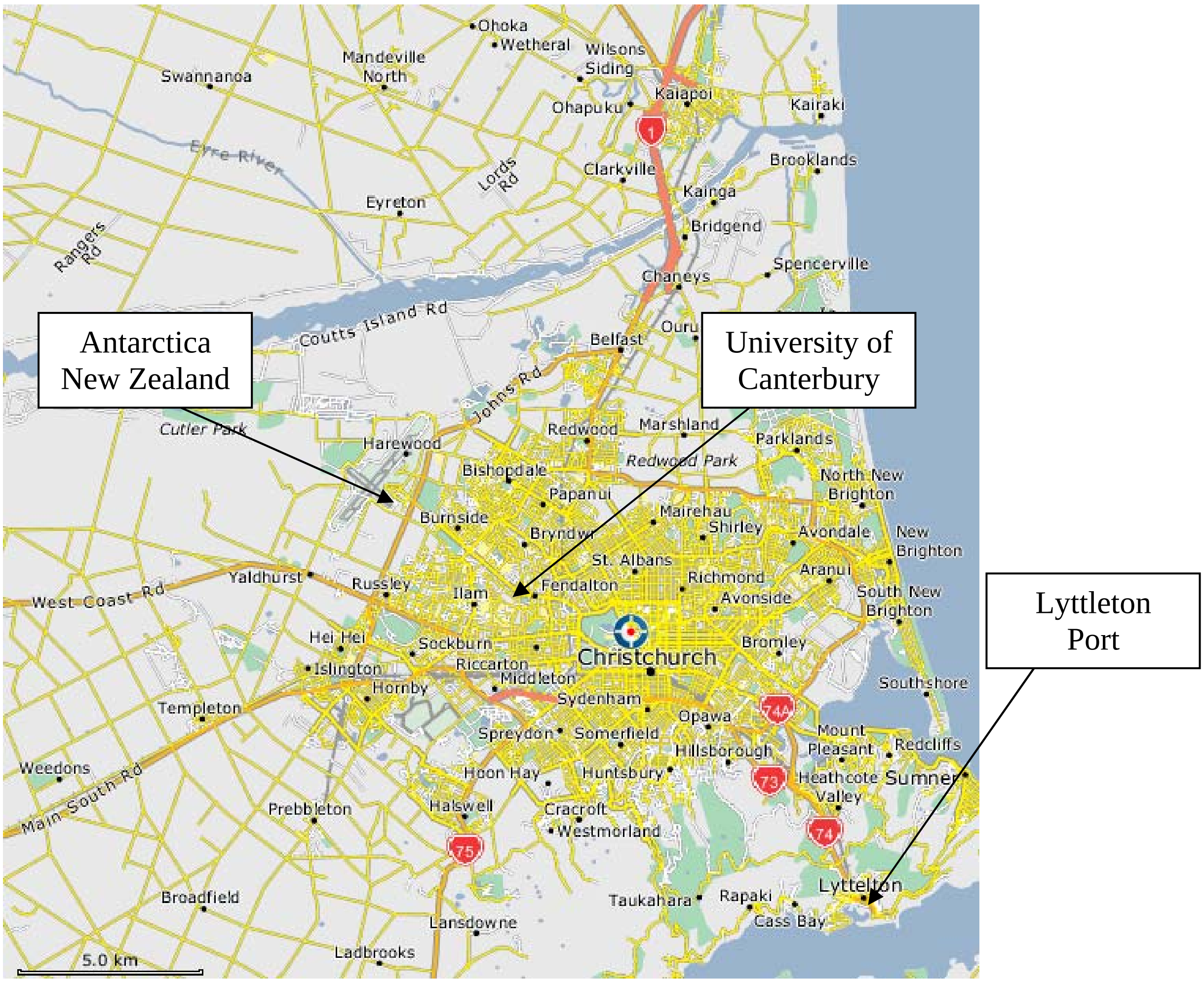

Figure 1.4 Christchurch is on the East Cost of the South Island of New Zealand. Antarctica New Zealand is situated in the suburb of Harewood[12].

Some research, including seed germination in glasshouses, was also carried out at the School of Forestry, at the University of Canterbury (Figure 1.4).

[12] www.wises.co.nz accessed on 05/05/06

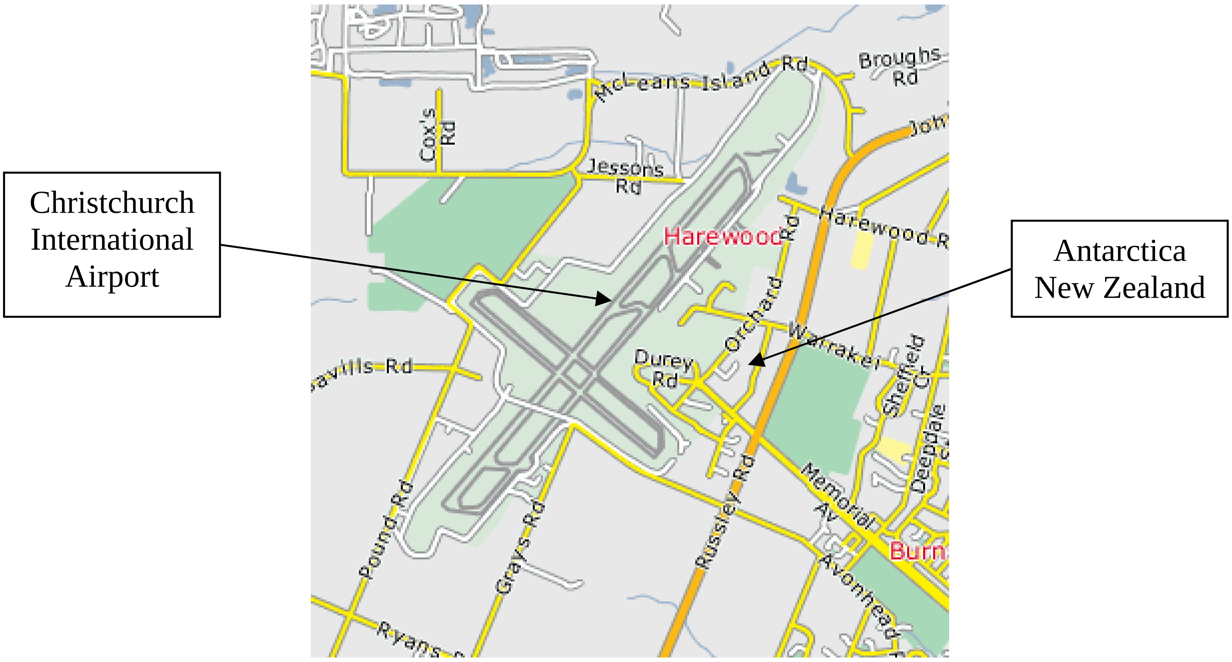

Figure 1.5 The location of Antarctica New Zealand on the fringes of Christchurch International Airport[13].

Antarctica New Zealand is located on the opposite side of Orchard Road to the International airport as shown in Figure 1.5.

The collection and storage on seeds found in the Antarctic was carried out at Antarctica New Zealand's Scott Base (Figure 1.6). Scott Base is located on Ross Island in the Ross Sea Region (Figure 1.7).

[13] www.wises.co.nz accessed on 05/05/06

Figure 1.6 Map of Antarctica. Antarctica New Zealand's Scott Base is located on Ross Island in the Ross Sea Region. The flight between Christchurch, New Zealand and Ross Island is the most efficient transport route for New Zealand, USAP and the Italian Antarctic Programme who also have bases in the same region[14].

[14] www.antarcticanz.govt.nz Ross Sea overview, State of the environment accessed on 01/06/06

Figure 1.7 Shows Ross Island. Scott Base is located on the Peninsula which is approximately 3 km to the USAP base McMurdo Station[15].

15 www.antarcticanz.govt.nz Ross Sea overview, State of the environment accessed on 01/06/06

2. Law and Policy

To establish the context of this study, I will consider the Antarctic Treaty and legislation from New Zealand and Australia in some detail, with particular reference to their application to the issue of biosecurity. This complex Antarctic Treaty System includes a large number of protocols and is outlined in Figure 2.1.

The umbrella under which all human activity in Antarctica is regulated is known as the Antarctic Treaty System. This system includes the Antarctica Treaty (1959), the Agreed Measures (1964), the Convention on the Conservation of Antarctic Marine Living Resources (CCAMLR) (1980), and the Protocol on Environmental Protection to the Antarctic Treaty (1991), also known as the Madrid Protocol. Although these treaties provide a framework for protecting the Antarctic environment, none specifically addresses biosecurity issues in the region. This issue will be discussed in detail later in the thesis.

2.1. Antarctic Treaty

The Antarctic Treaty was signed on 1st December 1959 in Washington. It came in to effect on 23rd June 1961 and covers all activity below 60° South. There are currently 44 signatories, 27 of these are Consultative members and the remaining 17 acceding states. The 12 original signatories to the Treaty were the Australia Argentina, Belgium, Chile, France, Japan, New Zealand, Norway, Russia (the former Soviet Union), South Africa, United Kingdom, United States of America. The purpose of the Antarctic Treaty is to ensure:

> *"in the interests of all mankind that Antarctica shall continue forever to be used exclusively for peaceful purposes and shall not become the scene or object of international discord"* .

New Zealand was one of the twelve original signatories and a claimant state. New Zealand has been very active in the development of the Antarctic Treaty System and has participated in all the Antarctic Treaty Consultative Meetings (ATCM). National programmes must act in accordance with the requirements set out by the Antarctic

Treaty and all regulations from protocols. The Antarctic Treaty itself has 14 articles which have the intention of protecting the wildlife and vegetation of this fragile environment. In addition the Treaty states that the Antarctic will be used for peaceful purposes, specifically prohibiting the establishment of military bases or weapons testing.

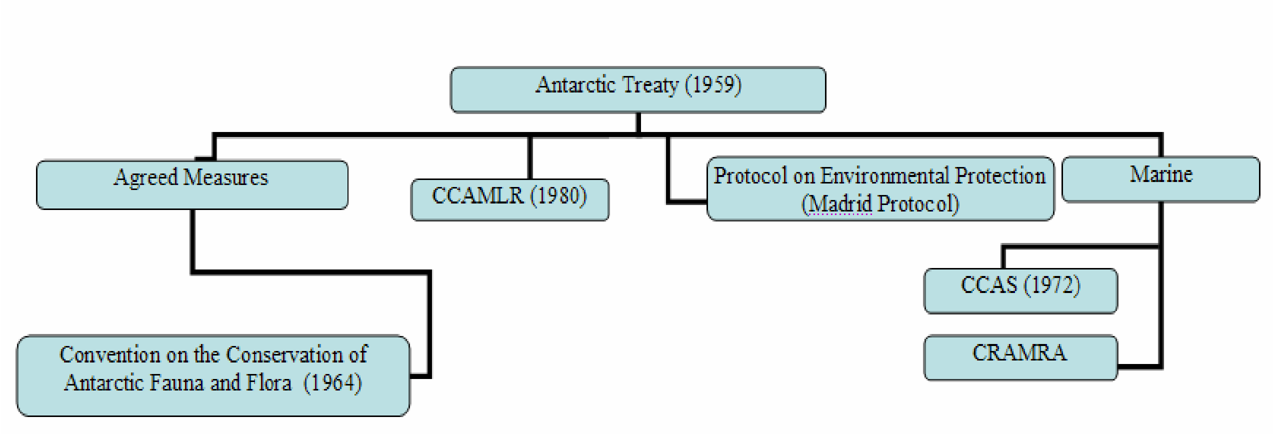

Figure 2.1 A diagrammatic representation of the Antarctic Treaty System.

The Antarctic Treaty provides protection against introduction from non-indigenous species through its articles and protocols. These include the Agreed Measure for the Convention on the Conservation of Antarctic Fauna and Flora (1964). Within the Agreed measures the Madrid Protocol in Annex II Article IV addresses unintentional introductions and states that permitted introductions must be removed and destroyed. It also acknowledges that a permit is required to remove or interfere with indigenous species. This Treaty also requires Environmental Impact Assessments (EIA) to be carried out prior to any activity being undertaken in the Antarctic, in order to minimise impact. Further protection is provided to Antarctic Specially Protected Areas (ASPA) by Annex V of the Madrid Protocol. An ASPA is an area designated to be free from human inference and can be assigned to environmentally delicate areas as well as historic sites and monuments.

Several fora have been set up to assist the development of the Antarctic Treaty. These groups include the Antarctic Treaty Committee Meetings (ATCM), Scientific Committee on Antarctic Research (SCAR) and Council of Managers of National Antarctic Programmes (COMNAP). These groups meet on an annual basis to discuss the issues surrounding the Antarctic and aim to develop relationships between inter-governmental and non-government organizations. Other organizations such as IAATO and the International Union for the Conservation of Nature (IUCN) are encouraged to join these meetings as experts in their fields.

The Antarctic Treaty does little to address unintentional introductions of non-indigenous species and more could be done in this area. Legally it is easier to control intentional introductions than unintentional introduction of non-indigenous species into the Antarctic. Therefore it is important to educate and encourage vigilance to prevent the unintentional introduction of species. Research has an important contribution to make in these efforts.

2.2. Agreed Measure for the Convention on the Conservation of Antarctic Fauna and Flora (1964)

The Agreed Measure for the Convention on the Conservation of Antarctic Fauna and Flora (1964) states in paragraph 25 that Parties will:

> "*avoid harmful interference with the normal living conditions of native mammals and birds, to control the introduction of non-indigenous species of plants and animals into the Antarctica Treaty area, and to take precautions to prevent the introduction of parasites and diseases into the area*" .

Despite the myriad of legislation outlined above which is intended to protect Antarctica, only the Convention on the Conservation of Antarctic Fauna and Flora (1964) provides any guidelines relevant to biosecurity. Even then, specific reference to biosecurity are not made. However, through the inclusion of phrases such as 'introduction of non-indigenous species' and 'prevent the introduction of parasites and diseases' the principals of biosecurity are incorporated.

2.3. The Convention on the Conservation of Antarctic Marine Living Resources

The Convention on the Conservation of Antarctic Marine Living Resources (1980) known as CCAMLR, came into force in 1982 managing all living resources in the marine environment. CCAMLR applies to the area between the Antarctic Continent in the South and the Antarctic Polar Front (50^{o}S) in the North. CCAMLR also gathers and publishes data on the status and changes in marine living resources, and the implementation of conservation measures. There were 24 members of the Commission which include Argentina, Australia, Belgium, Brazil, Chile, European Community, France, Germany, India, Italy, Japan, Namibia, New Zealand, Norway, Poland, Republic of Korea, Russia, South Africa, Spain, Sweden, Ukraine, United Kingdom, United States of America, and Uruguay. A further eight states acceded to CCAMLR but are not members including Bulgaria, Canada, Greece, Finland, Mauritius, Netherlands, Peru and Vanuatu. Australia has used this Convention to enhance its influence in the Antarctic Treaty System to boost its reputation as a responsible manager of marine resources[16].

CCAMLR was established due to concerns over increasing krill catches in the Southern Ocean and the impact these catches may have on the population of krill and ultimately on other marine life dependent on krill, including birds, seals and fish. The Commission takes a cautious approach to harvesting in order to minimise risks associated with unsustainable practices in conditions of uncertainty. New Zealand plays its role as a member of the CCAMLR Commission by its command in the Ross Sea Region of the Southern Ocean[17]. The Convention has three main principles; to prevent the decrease of any harvested population below a sustainable level, to maintain the ecological balance between harvested dependent and related populations and restore depleted populations, and to prevent non-reversible changes in the marine

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[16] www.aad.gov.au Introducing CCAMLR accessed on 13/04/06

[17] http://www.antarcticanz.govt.nz/article/3413.html#2654 Accessed from the Antarctica New Zealand website on 22/09/05

environment. However, CCAMLR (1980) does not make any comment on the protection of marine life, nor the introduction of non-indigenous species, therefore has limited implication to biosecurity.

2.4. Protocol on Environmental Protection (Madrid Protocol)

As outlined above and seen in Figure 2.1, the Protocol on Environmental Protection (Madrid Protocol) was developed to protect the Antarctic environment and ensure the safe and careful use of its resources. The Madrid Protocol of the Antarctic Treaty was signed on 4th October 1991 and came into force on 14th January 1998 following ratification by all 26 Antarctic Treaty Consultative Parties. The Committee on Environmental Protection (CEP) was then established to advise and oversee the activities within the Madrid Protocol. To ensure the Madrid Protocol had legal recognition within New Zealand, legislation was introduced as the Antarctica (Environmental Protection) Act 1994 and came into force in February 1995.

The Madrid Protocol (1991) replaced the earlier Agreed Measures and provided a more comprehensive approach to the protection of the Antarctic environment. The Protocol designates Antarctica as a ‘natural reserve, devoted to peace and science’. It establishes environmental principles for the conduct of all activities and prohibits mining. The Madrid Protocol (1991) subjects all activities to prior assessment of their environmental impacts, provides for the establishment of a Committee for Environmental Protection to advise the Antarctic Treaty Consultative Meetings (ATCM), and requires the development of contingency plans to respond to environmental emergencies. Finally, the protocol provides for the elaboration of rules relating to liability for environmental damage.

2.5. New Zealand legislation

Member states of the Antarctic Treaty are bound not only by the International Law mentioned above but also by domestic legislation. New Zealand has had sovereignty over Ross Sea Dependency since 1923. The Ross Sea Dependency is the area below

60° South and bounded by 160° East and 150° West (Figure 2.2). The Antarctica Act of 1960[18] means that New Zealand laws apply to all those within the Ross Sea Dependency, and also to any New Zealand citizen or resident anywhere in the Antarctic. Therefore, New Zealanders entering Antarctica are bound by the Biosecurity Act (1993) and the Antarctica (Environmental Protection) Act (1994). If a New Zealander travels to Antarctic under the auspices of Antarctica New Zealand, in addition to New Zealand legislation, they must also abide by the rules and regulations set by Antarctica New Zealand and all international protocols from the Antarctic Treaty System. Overall, any signatory country to the Antarctic Treaty must meet the requirements set out in their countries' national laws and policies, even where these are more restrictive than the Antarctic Treaty.

[18] Accessed on the 07/05/06 http://www.legislation.govt.nz/libraries/contents/om_isapi.dll?clientID=88998&infobase=pal_statutes.nfo&jump=a1960-047&softpage=DOC

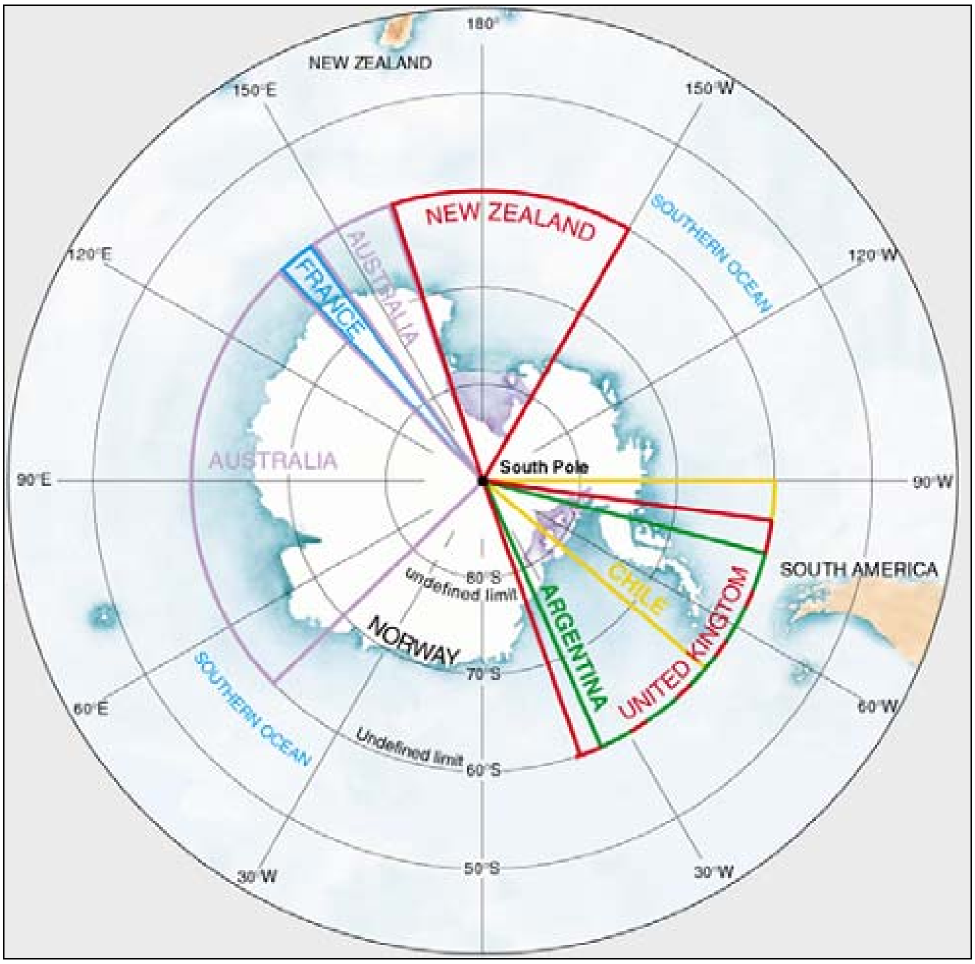

Figure 2.2 Diagram of areas of Antarctica claimed by nations with particular reference to the Ross Sea Dependency of New Zealand (Waterhouse & Antarctica New Zealand, 2001)

2.5.1. New Zealand Biosecurity Act (1993)

The aim of the Biosecurity Act (1993) was to exclude unwanted organisms from New Zealand. The Act prohibits the importation of plants, animals, micro-organisms or animal products without a permit. This also applies to mediums which could carry unwanted organisms such as water and soil. The Act does not mention Antarctica as part of the areas of concern. By implication, however, this Act applies to the movement of plants, animals and animal products to and from Antarctica due to the requirement outlined above.

The New Zealand Biosecurity Act provides a more rigorous biosecurity protection compared with the Antarctic Treaty, but only applies to those areas of Antarctica under New Zealand's control. Other nations with interests in Antarctica have national policies which are more extensive than the Antarctica-wide protocols. For example, Australia has implemented extra provisions based on their home laws, which are discussed in section 2.6.

2.5.2. Antarctic (Environmental Protection) Act (1994)

The purpose of the Antarctica Act (1994) was to protect the Antarctic continent and maintain the importance of the area for scientific research[19]. Under this Act the Ministry of Foreign Affairs and Trade (MFAT) has responsibility for enforcing the law which prohibits the following activities without permission:

- Entering or carrying out activities in a protected area;
- Taking or attempting to take any native bird or mammal;
- Removing or damaging native plants in quantities which significantly affect local distribution or abundance;
- Harmfully interfering with native plants, mammals, birds or invertebrates;
- Introducing any species of animal, plant or micro-organism not native to the area;
- Importing non-sterile soil.

The Antarctic Act therefore does address the illegal introduction of non-indigenous species into Antarctica, although it does not state how the provisions of the Act would be given effect. This therefore becomes the responsibility of Antarctica New Zealand, who generate their own policies to meet the requirements of the Antarctic Act (1994).

2.5.3. Antarctica New Zealand Policy

Under Antarctica New Zealand all domestic waste including sewage and cleaning products are UV and biologically treated before being released into the sea. All other waste including recyclables, hazardous and general waste is returned to New Zealand. It is then disposed of as if it were locally generated rubbish.

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[19] http://www.antarcticanz.govt.nz/article/3284.html#4048 accessed on 13/02/05

It is important to note that even though MAF and customs inspections are carried out at Christchurch International Airport upon arrival into New Zealand, inspections are not conducted upon arrival in the Antarctic.

2.6. Australia

Australia is considered to be a leader in the domain of biosecurity. By comparison with New Zealand, Australia has a longer tradition of biosecurity research. Australia has also been more generously funded by central government through the Australian Antarctic Division (AAD) compared to New Zealand. The AAD appears to have worked effectively with other Australian government departments such as Customs, to produce robust management plans. Australia and New Zealand share a similar concern for the strength of their border control. Both countries have this interest in common and as they share the benefit of being surrounded by water, it seems possible that New Zealand could learn some lessons from the activities of Australia with regard to biosecurity and Antarctica.

The AAD have decided to adopt a strict approach to the protection of the Antarctic environment; their policy '*Take it new or keep it clean*' reflects this. The AAD advocates strict quarantine methods for visitors to sub-Antarctic and Antarctic stations. Research conducted in 2000/01 found soil, insects and various types of plant material amongst cargo arriving in Antarctica from Australia. In response to this study by Dr Dana Bergstrom[20] on behalf of the AAD, the AAD improved their cargo handling practices and quarantine officers are appointed to each voyage. For example, at sub-Antarctic Heard Island, AAD has modified their clothing to protect the 'pristine environment' so that only new clothing is utilised. Clothing design was modified to minimise seed entrapment. The new designs have no Velcro and the fabric is not open-weave so seeds and insects can easily be cleaned off the clothing.

[20] www.aad.gov.au accessed on 06/09/05

2.6.1. Australian law

Each country is responsible for implementing the protocols and regulations set out by the Antarctic Treaty in that country's laws, and in the Antarctic Programme's policies and guidelines. In Australia, like New Zealand, there are a number of laws which relate to the biosecurity issue. For ease of reference I have outlined them in Figure 2.3. In this section I will consider the legislation which is relevant to biosecurity.

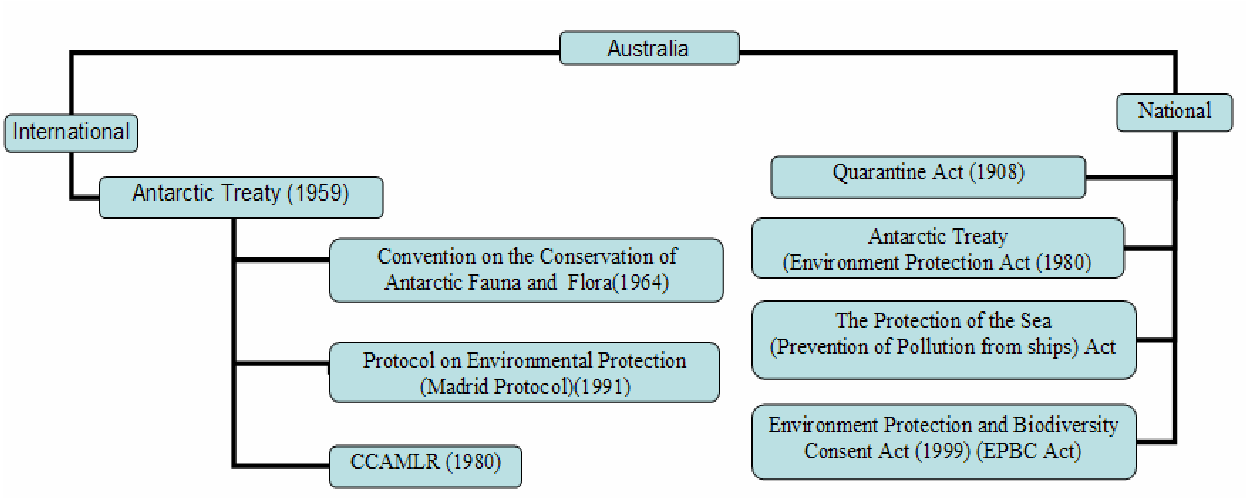

Figure 2.3 Australia's international and national regulations that cover Australian activities in the Antarctic[21].

The Quarantine Act 1908 is implemented by the Australian Quarantine Inspection Services (AQIS) on behalf of the Ministry of Agriculture, Fisheries and Forestry. The Act requires all biological material, soil, ice and water samples to be checked on return to Australia from both the Antarctic and sub-Antarctic. This is monitored by way of the permit which must be applied for before each person sets out on an expedition to the Antarctic. The collection of geological samples require notification to AQIS but no permit is necessary. A sample 'in transit' via Australia to another country must be included on a Quarantine Manifest but does not require a permit.

Management measures for the Madrid Protocol, the Agreed Measures for the Conservation of Antarctic Fauna and Flora, and the Convention for the Conservation

[21] www.aad.gov.au Australian Law accessed on 06/05/06

of Antarctic Seals are implemented in Australian law under the Antarctic Treaty (Environment Protection) Act (1980) and by the utilisation of EIA and waste management regulations. The Conservation of Antarctic Fauna and Flora is given protection under Article 3 of Annex II to the Madrid Protocol by using a permit system.

A permit system regulates activities in the Antarctic Treaty Area and restricts the killing or taking of animals and plants, terrestrial and freshwater invertebrates. It prohibits interference or disturbance of birds by people on foot, in vehicles, ship or aircraft. The permit restricts entry into protected areas and prohibits damage to huts, monuments and historic areas. Permits are used to manage the introduction of non-indigenous species such as animals, plants, viruses, bacteria, yeasts and fungi.

There are several activities under the Antarctic Treaty (Environmental Protection) Act 1980 for which permits will not be issued and which relate to biosecurity. They are the introduction of non-sterile soil, activities that adversely modify a habitat of native fauna and flora. Pesticides are not allowed in the Antarctic except for scientific, medical or hygiene purposes. Permit holders are required under the Antarctic Treaty (Environmental Protection) Act 1980 to report to the Environmental Policy and Protection Section within 30 days after the expiration of the permit. The Act provides limited powers of arrest and seizure by appointed inspectors including the leaders of Antarctic voyages and stations, field leaders and other appointed inspectors.

Australia’s national environmental protection law is the Environment Protection and Biodiversity Conservation Act 1999 (EPBC Act). The EPBC Act covers most activities carried out in the Antarctic. The marine environment has protection under CCAMLR. Australia has created the Antarctic Marine Living Resources Conservation Act and the Protection of the Sea (Prevention of Pollution from Ships) Act to meet their requirements under CCAMLR.

Australia also has obligations under MARPOL (Marine Pollution). The MARPOL convention is a combination of two treaties in 1973 and 1978[22]. MARPOL is the International Convention for the Prevention of Pollution from Ships. This convention is in force in 127 countries preventing ship pollution in the marine environment from accidents such as collisions or groundings as well as “operational waste”.

In addition to its commitment to issues of biosecurity relevant to the Antarctic continent, Australia also has control over several sub-Antarctic Islands including Heard and McDonald Islands. The sub-Antarctic has greater biodiversity than the Antarctic due to a milder climate. Therefore management plans and legislation need to simultaneously represent the differences found in the two regions. The regulations controlling the activities of those who visit these Islands include the Heard Island and McDonald Island Act, the Environmental Protection and Management Ordinance, the EPBC Act (1999), the National Parks and Reserves Management Act (2002) and the Environment Management and Pollution Control Act (1994). As the sub-Antarctic Islands are beyond the scope of this research I will not consider these regulations in detail. However they highlight the way in which the AAD have modified their actions to protect the different climatic environments in this region.

2.6.2. Cargo

Cargo is defined as work equipment, personal effects, dangerous goods and mail[23]. All voyages that touch the ice in the Antarctic are considered as overseas voyages. The movement of goods from international destinations via Australia to Antarctica are considered ‘in transit’. The Australian Antarctic Division (AAD) is a licensed Customs Bond Store and therefore able to hold cargo in transit before it continues on to the Antarctic. During their time in the Customs Bond Store, the goods can not be accessed so that nothing can be added, removed or altered.

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[22] http://www.maritimenz.govt.nz/Pollution/marpol.asp accessed on 03/05/06

[23] www.aad.gov.au Cargo accessed on 05/05/06

Domestic cargo is defined as the movement of goods between Australia and the Antarctic. All goods shipped by the AAD must comply with strict requirements of Customs. On the return voyage from Antarctica, a manifest and subsequent clearance occurs once the ship returns to Australia. If clearance cannot occur the goods are held on Macquarie Wharf (M4) in Tasmania.

The AAD developed an Environmental Management System (EMS) which provided the catalyst for changes at M4. The AAD conducted EMS audits and concluded that during the past two summer seasons (2002/03 and 2003/04) the number of contaminants contained within the cargo has greatly reduced due to regular fumigation, diligent checking and cleaning of cargo. The areas AAD identified as problematic were machinery, shipping containers and gas bottles. These items are now more thoroughly checked. Processes and packing have also been improved to meet the new higher standards [24].

Passengers on voyages to the Antarctic from Australia are encouraged to check their personal gear for any prohibited items or anything that could have a negative impact on the Antarctic environment. A vacuum cleaner is set up at the departure points to clean clothing and bags as well as for the cleaning of boots. AAD emphasises the importance of no plants, animals or soil going on to the Antarctic continent. Passengers are also encouraged to be vigilant for rodents and insects and to report any undesirable species to management staff.

Due to the fact that not all Southbound AAD voyages were covered by Australian legislation, the AAD has established a Memorandum of Understanding (MOU) with Quarantine Tasmania to ensure high standards of quarantine are maintained. Quarantine officials and Quarantine sniffer dogs are used to carry out regular checks of the vessels, cargo, shipping containers and wharf areas for pests and other contaminants. Every vessel is checked by Quarantine officials on the day of departure and every cabin and all personal effects are checked when the passengers board the vessel.

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[24] www.aad.gov.au Environmental Issues cited on 13/04/06

2.6.3. The Keep it Clean! Campaign

Following concerns that plant and animal material could be introduced to Macquarie Island research was carried out by AAD on clothing and cargo. As a result the *'Take it new or keep it clean'* campaign was established[25]. This campaign was prompted by two studies, the first in the 2002-03 season, and the second was a repeat in the 2004-05 season. One of these studies[26] found that on a single voyage to Macquarie Island 960 seeds were found in the clothing, equipment and the footwear of expeditioners. The seeds were removed and returned to Hobart for germination experiments and 150 germinated seeds were identified as weeds, grasses, sedges and flowering plants from all around the world[27]. These studies are of great importance, as they suggest that large volumes of plant material and other contaminants are moving between Australia and the sub-Antarctic via the movement of cargo, people and clothing. My study will explore if this scenario applies to the movement of people and cargo between New Zealand and Antarctica.

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[25] www.aad.gov.au *Take it new or keep it clean* cited on 13/04/06

[26] www.aad.gov.au Plants and Animals, Keep it clean! Cited on 13/04/06

[27] www.aad.gov.au Plants and Animals, Keep it clean! Cited on 13/04/06

3. Methods

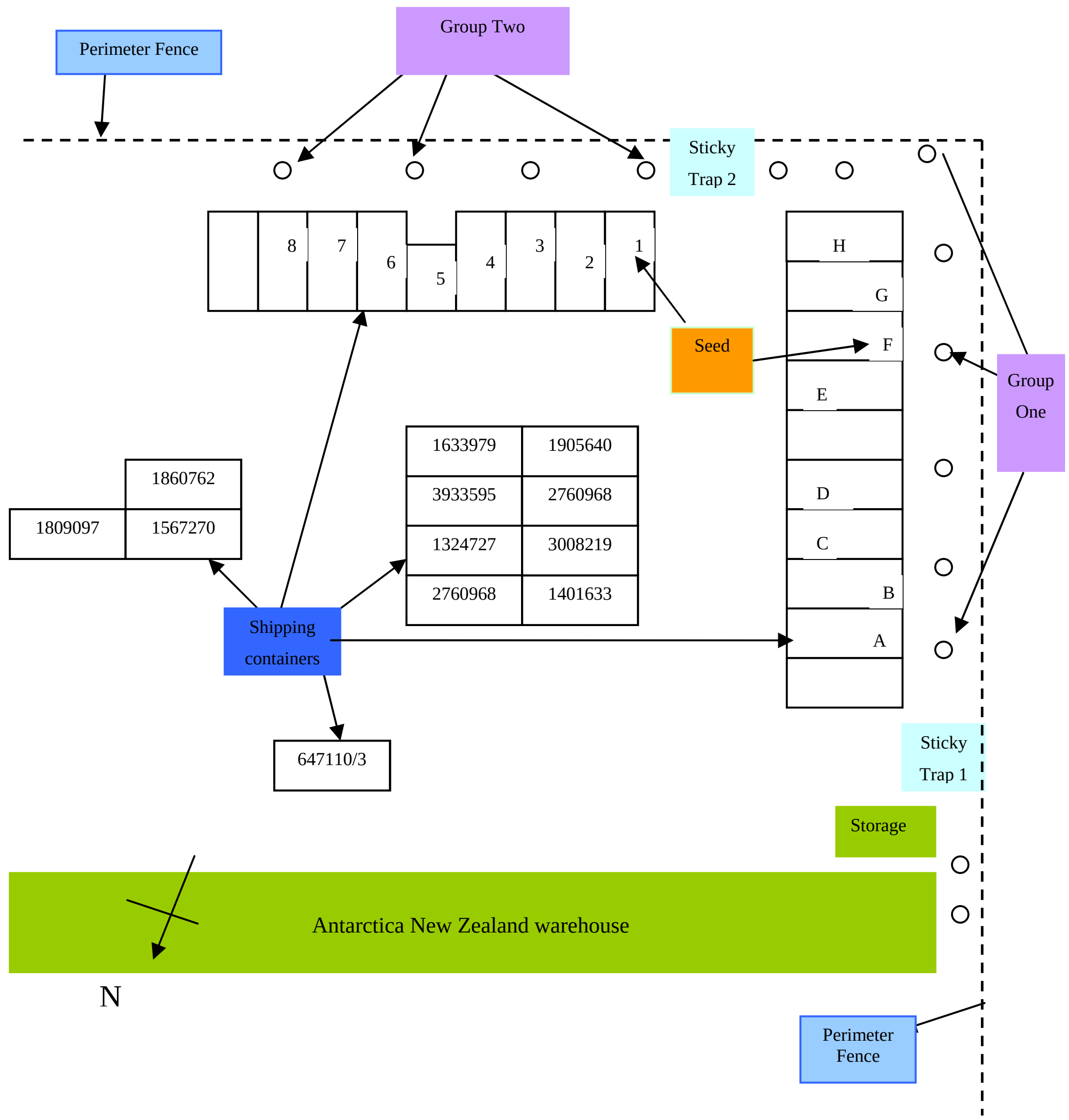
Five methods of data collection were used across four different vectors to explore the potential movement of contaminants between New Zealand and Antarctica. The methods of data collection used were manual inspections, seed trays, seed traps, sticky traps and soil samples. The four vectors sampled were shipping containers, clothes, fresh produce cargo, and soil. The data collected in New Zealand involved sampling the containers (exterior and interior), clothing, and fresh fruit and vegetable cargo prior to dispatch to Antarctica. Soil samples were taken at Scott Base and McMurdo Station in Antarctica. I will outline each of these methods in detail and describe the locations in which the data were collected.

3.1. Shipping containers – storage area

To investigate the presence, or absence, of seeds on shipping containers four methods of data collection were used; seed trays, seed traps, sticky traps and hand searching/manual inspection. The data collection was conducted at Antarctica New Zealand’s Christchurch base where shipping containers are stored for the months prior to being loaded for their journey to Antarctica. Some of the same containers that are loaded to go to Antarctica are also utilized on other projects in the intervening months between the Antarctic seasons. An example is discussed later in the chapter. The layout of the storage area and the location of the various seed collection methods are outlined in Figure 3.1.

The different seed trapping methods were chosen to detect the amount of seed blown at, or on to the containers. By using three different types of seed collection, the weaknesses of each approach could be overcome through triangulation of data, thereby providing more accurate results.

Species identification was initially undertaken by visual examination using reference material to assist, and in the case of the seed trays, confirmed through seed germination.



Symbols:
O = Seed traps (14)
A-H = Seed trays (8) (Group One)
1-8 = Seed trays (8) (Group Two)

Figure 3.1 The diagram shows the layout of the container storage area at Antarctica New Zealand and placement of data collection methods used in this study. The containers shown with serial numbers are those that were sent to Antarctica. The single letters and numbers refer to the seed trays, and assisted sample identification. The O symbol around the perimeter of the storage area marks the position of the seed traps. The location of the two sticky traps are also indicated. The shipping containers that had the seed trays placed on top did not go to the Antarctic in the 2005/06 season

3.2. Shipping Containers - Seed Trays

The seed trays were placed on top of the shipping containers to trap seeds travelling at 2.5 metres, that is seeds that are likely to lodge in the gutters of the containers. Only one trap was placed on each shipping container. As the seed trays collect the seeds in soil, this method allows for easy germination of the seed, which could then be used for species identification.

Sixteen polystyrene trays were used, each 420mm x 360mm, with holes drilled in the base to provide drainage. String was fed through the base of the trays to allow them to be fixed to the container using duct tape.

Shade cloth, 430mm x 430mm, was used to line the trays, as shown in Figure 3.2. This was incorporated so that in the event of heavy rain, any loss of seed and soil through the drain holes would be minimised, whilst also allowing the water to drain away. The soil; a bark and peat combination was approximately 50mm deep. To reduce the chance of interference by birds the trays were covered using PVC welded square mesh 20mm x 20mm x 1.00mm, secured to the tops of the trays. Once the trays were lined, filled with soil and covered with mesh, and labelled for tracking, the trays were placed on the roof of the shipping containers (2.5m above ground level) as shown in Figure 3.3.

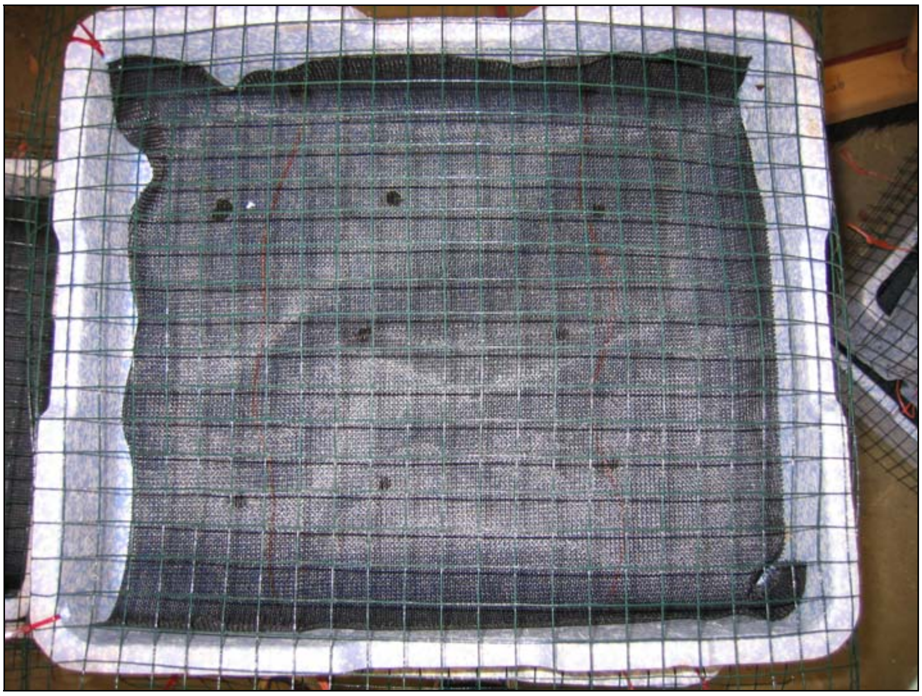


Figure 3.2 A seed tray prior to being filled with soil but showing the bird mesh fitted. The seed trays were then placed on top of the shipping containers at Antarctica New Zealand and two controls at the School of Forestry, University of Canterbury (Photograph by A. Fortune).

The seed trays were located at two sites: Antarctica New Zealand's Christchurch base (experimental condition) and two control trays placed behind the School of Forestry at the University of Canterbury. The control trays were identical to those at Antarctica New Zealand, but placed in an area of known high seed fall to provide proof of the effectiveness of this method.

Trays at Antarctica New Zealand were arranged in two banks of samples - one bank given numerical identifications (1-8) also known as Group One and the other alphabetical identifications (A-H) also known as Group Two. The control trays were labelled as X and Y. The two banks of trays were at right angles to each other (as shown in Figure 3.1), to make it clear which sample came from each set of containers, and to account for prevailing weather conditions if necessary.

The containers chosen to have the seed trays placed on them were identified by Antarctica New Zealand staff as those being sent to Antarctica that season (2005/06). However, it later became apparent that in fact a different block of newly arrived containers at Antarctica New Zealand were actually being sent to the Antarctic. Given the containers were all in the same storage area, the conditions would have been very similar for those which were sent and for those that remained. Hence it was not thought to be critical which containers the seed trays were located upon.

The seed trays were watered every second day to maintain the moisture level within the soil and to assist with germination. The trays were left for four weeks and then transferred to a glasshouse at the University of Canterbury for germination. Conditions in the glasshouse were desirable for germination and also prevented further seed collection. In addition the shipping containers were about to be moved. Once in the glasshouse the mesh was removed from the seed containers to prevent the seedlings from tangling in the mesh. The seed trays were left in the glasshouse for four weeks to allow germination to occur. After four weeks the experiment was stopped due to time restrictions.

Figure 3.3 An example of a seed tray on top of a shipping container at Antarctica New Zealand, Christchurch. The growing medium, bird protection mesh and string protruding from the sides are all visible (Photograph by A. Fortune).

3.3. Shipping containers - seed traps

The second data collection method used in the container storage areas was seed traps. Seed traps provided a method of collecting seeds at a different height to the other methods (i.e. 800mm above ground level). The seed traps were kindly provided by Ensis (formerly known as the Forest Research Institute).

Fourteen seed traps were spread approximately five metres apart along the perimeter of the cargo handling area, within the grounds of Antarctica New Zealand as shown in Figure 3.1. At each location one seed trap was set up and fixed into the ground using wooden stakes 800 mm from the ground to the rim of the funnel (Figure 3.4). The upper portion of the traps consisted of a plastic funnel with a diameter of 600mm. Beneath the funnel was a plastic tube to catch the specimens, with fine mesh at the base to retain the seeds and allow any water to drain out. The water was allowed to drain to reduce the chance of seeds being water damaged, which would have made identification more difficult.

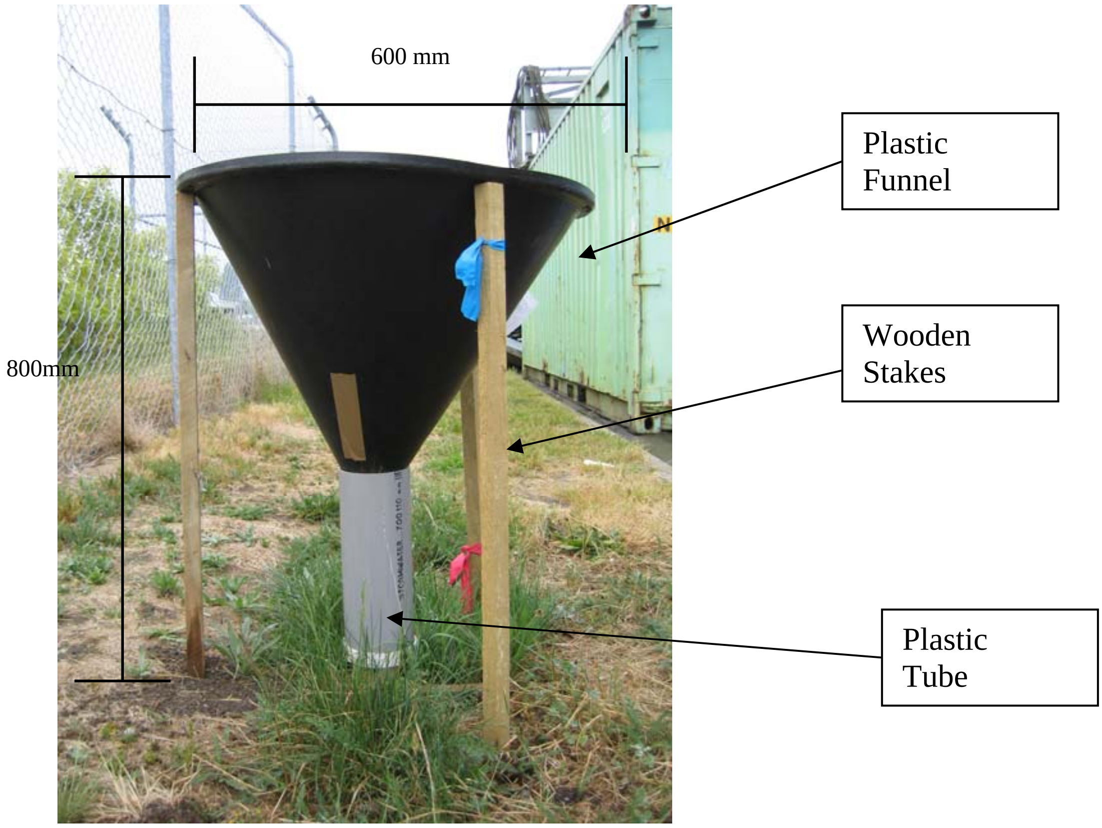


Figure 3.4 Photograph of a seed trap set up at Antarctica New Zealand. The seed traps were located around the perimeter of the grounds in the same area where the shipping containers were packed prior to departure (Photograph by A. Fortune).

The seed trap collection containers were cleared after four weeks; samples were removed and the traps reinstated for a further four weeks. When the samples were removed from Antarctica New Zealand, the containers were rinsed out into two sieves with meshes of 1.00mm and 0.50mm. A tray was placed underneath to catch any other material contained in the sample. This allowed the samples to be divided into large and small specimens, to help with identification. Intact insects were then picked out of the large debris sample and placed in a separate paper bag. The samples were subsequently rinsed into a small plastic container with warm water to help remove any soil present, and then drained using a water jet suction pump lined with number one filter paper (Figure 3.5). The container was then washed and the process repeated. The filter paper was then placed in a labelled paper bag and placed in the oven at 40^{o}C for 24 hours to remove any water. The samples were then taken out of the oven for identification of the seeds and pieces of insects. Following each sample all equipment was thoroughly cleaned to ensure there was no cross contamination.

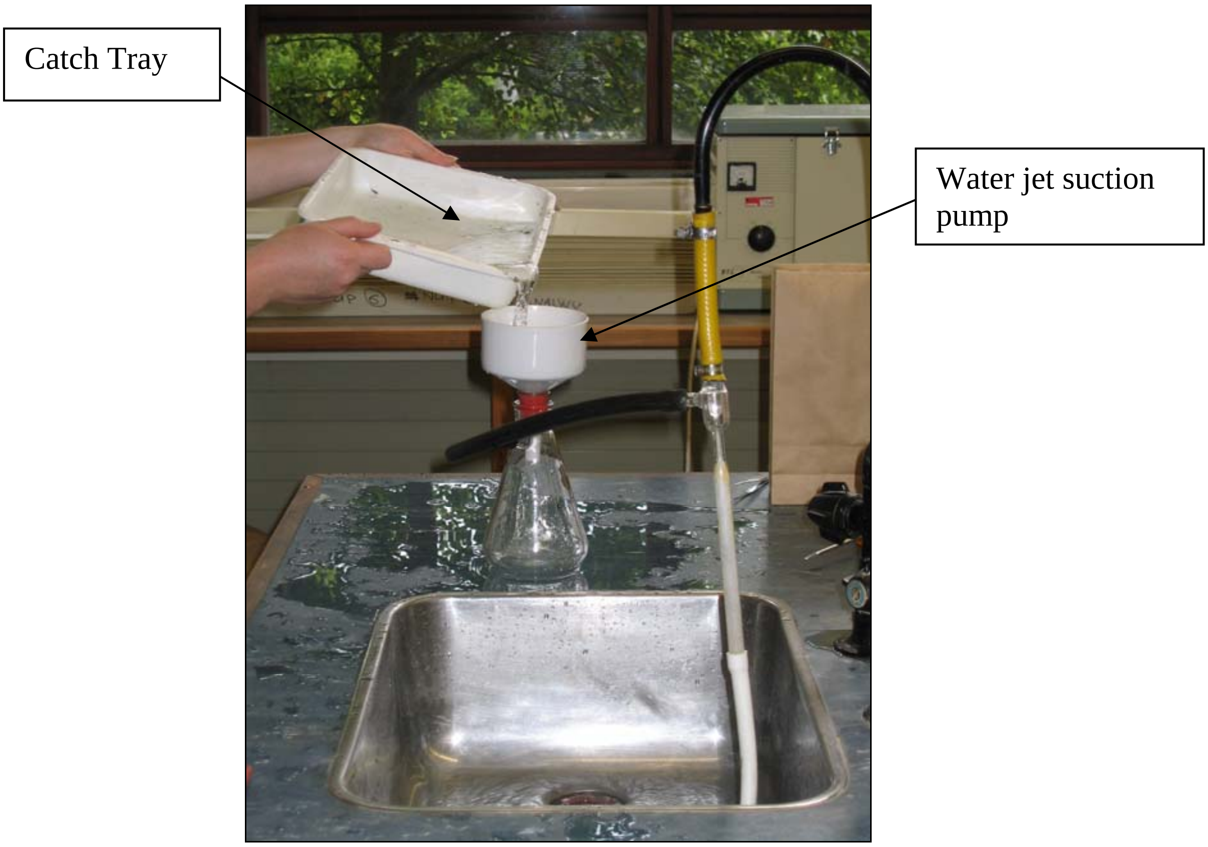


Figure 3.5 A sample from the seed traps is poured into a water jet suction pump which extracts the excess water, leaving behind the sample material collected. It is a fast and efficient way of removing large volumes of water without losing any sample material (Photograph by C. Tisch).

3.4. Shipping containers - sticky traps

This technique is most commonly used for catching insects but is also useful for trapping small seeds. Sticky traps were constructed from cardboard, covered on both sides with Duraseal. They were located on the perimeter fence of the container storage area, as shown in Figure 3.6. The sticky sides of the Duraseal faced outwards and were then covered with mesh (20mm x 20mm x 1.00mm) to hold the Duraseal in place. Each sticky trap was then tied to the fence bounding the container storage area.

The sticky traps were located with their centres 1.8m above the ground. This height was chosen, as it was roughly the midpoint between the height of the seed traps on the ground and the seed trays on the top of shipping containers. Sticky traps were located in the horizontal gap between the containers to allow them to catch any seed which passed between the containers that had not been caught in either the seed trays or seed traps as shown in Figure 3.1. Each side of the sticky trap was labelled either A or B for ease of identification.

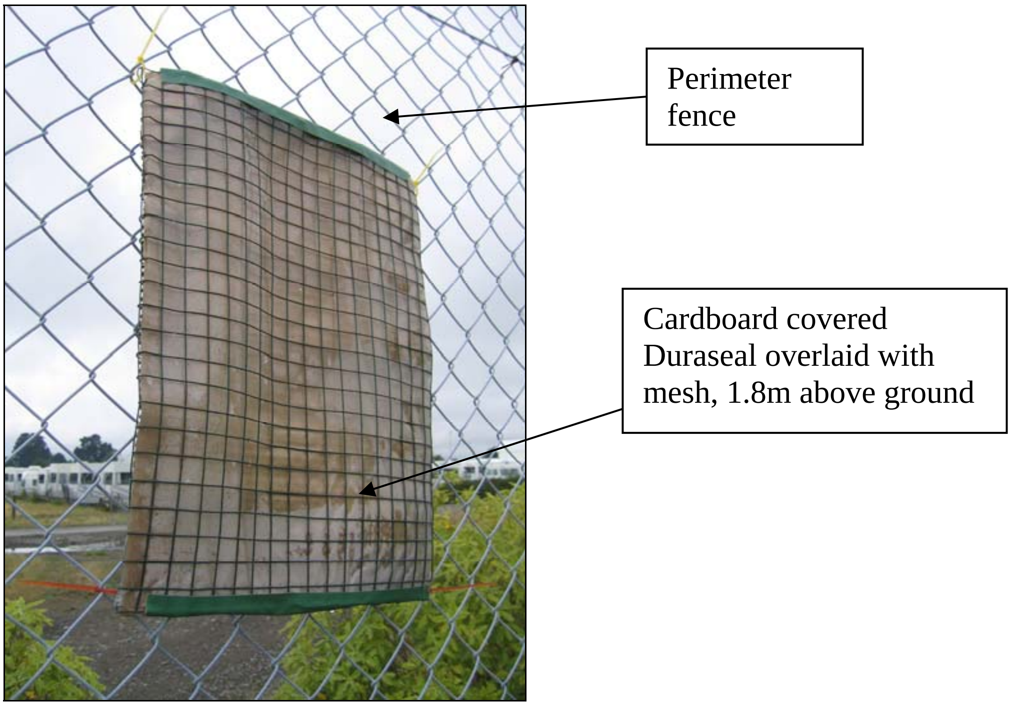


Figure 3.6 Sticky traps located at Antarctica New Zealand attached to the fence where the shipping containers were stored (Photograph by A. Fortune).

It is possible the mesh may have been too small to allow larger seeds to pass through and be caught on the Duraseal. However, most large seeds are not transported by wind due to their weight. This data collection method was in place for four weeks. The sticky traps were removed and a survey of the sheets was carried out. All seeds or insects were recorded and identified where possible.

3.5. Shipping containers - manual inspection

An external inspection of the shipping containers was conducted including the edges, roof drains and corners, before they were transported by road to Lyttleton to be loaded onto ships to be transported to Antarctica. Collection method is shown in Figure 3.7. Any contaminants were extracted using tweezers and brushes and stored in plastic bags and labelled. The locations of the containers and faces available for sampling are shown in Figure 3.1. Some faces of the shipping containers were not accessible and the containers could not be repositioned during the study. Inspection of these surfaces was therefore impossible. All accessible faces of all the containers being sent to Scott Base by Antarctica New Zealand were sampled, which gave a sample size of 12. All material removed from the containers was weighed to establish the extent of soil collected on each container.

Figure 3.7 Manual inspection of the shipping containers at Antarctica New Zealand. Twelve containers were externally inspected using this technique (Photograph by A. Fortune).

3.6. Inspection of clothing

Clothing supplied to members of the New Zealand Antarctic Programme by Antarctica New Zealand prior to departure for Antarctica was inspected. Clothing and footwear are re-used after each expedition. When items are worn out or damaged they are discarded and new additions to the pool are purchased. The clothing and footwear were checked for the presence of seeds and other contaminants to investigate this as a possible pathway of invasive species travelling to the Ross Sea Region. The entire garment was checked, including pockets, Velcro and seams. This inspection took place after the garments and footwear had been cleaned and prior to its distribution to participants of the New Zealand Antarctic Programme. This process was conducted at the Antarctica New Zealand store in Christchurch. Seeds or vegetation located were removed using tweezers and a small brush. Contaminants from each item were stored in individual plastic bags for later identification with a microscope. Photographs of some of the standard issue items are shown for illustrative purposes (Figure 3.8).

A sampling frame was generated based on a standard issue kit, taking a sample of 20 items of each type (Table 3.1). Only 15 pairs of thermal gloves were sampled as this was the entire stock available at the time the study. Some of the clothing and footwear had already been worn and some items were new. Both categories were sampled.

Table 3.1 A list of standard issue kit given to all staff going to Antarctica and the total number of each item sampled. All clothing is stored at Antarctica New Zealand warehouse prior to issue to participants.

Type of clothing	Number of items sampled
Balaclava, wool	20
Cap, windproof lined	20
Headband	20
Jacket, survival	20
Salopettes, survival	20
Jacket/anorak, windproof	20
Salopettes/trousers, windproof	20
Jacket, thermal	20
Salopettes/trousers, thermal	20
Shirt, thermal	20
Vest, sleeveless	20
Boots, Sorel (including liner) (pairs)	20
Boots, Mukluk (pairs)	20
Liners for Mukluk boots (pairs)	20
Gloves, wool (pairs)	20
Mitts, wool (pairs)	20
Mitts, windproof lined (pairs)	20
Gloves, thermal (pairs)	15
Bag carryall	20

The Antarctica New Zealand store contains a wide variety of Antarctic clothing both standard issue and more specialised equipment (low-issue). Standard issue clothing was considered the most appropriate to examine as it is provided to every participant and therefore has the highest level of usage. By comparison the low-issue specialised items in the inventory (such as the helicopter jumpsuits) were not held in large enough quantities to be considered a representative sample for this study.

Extreme Cold Weather (ECW) Jacket   Mukluks, outdoor ECW footwear

Figure 3.8 Two examples of standard issue Antarctic field clothing given to participants of the New Zealand Antarctic Programme and examined in this study. (Photograph by A. Fortune)

3.7. Airborne - cargo

The intention was to carry out inspections of a sample of pallets transported by air to Antarctica. These pallets usually contain baggage and equipment being transported with personnel.

3.8. Aeroplanes

It was also intended that internal and external checks of the Royal New Zealand Air Force (RNZAF) planes would be conducted prior to departure for Antarctica subject to airport security restrictions.

3.9. Airborne - pallets of ‘freshies’

Fresh fruit and vegetables, commonly known as ‘freshies’, are dispatched to Scott Base every two weeks during the summer season. The freshies are sourced from a local Christchurch supplier and arrive at the dispatch point in the form shown in Figure 3.9. They are then loaded on to travel crates and transported by air.

Visual inspection of the freshies was undertaken immediately after delivery to Antarctica New Zealand in Christchurch, and also prior to their re-packing for the flight. A sample of 30 boxes was visually inspected, including searches between the leaves of vegetables such as lettuces, cabbage and broccoli. Samples of contaminants found within the freshies were collected with tweezers and placed in sealed plastic bags for further identification. Internal and external examinations of the travel crates used for freshies were also completed.

Figure 3.9 A large volume of fresh fruit and vegetables are transported to Scott Base by air on a regular basis throughout the summer season. The boxes in this illustration were received from the supplier and were awaiting packing prior to being air lifted to Scott Base (Photograph by A. Fortune).

3.10. Scott Base – soil samples

Soil sampling was undertaken by Antarctica New Zealand staff on my behalf at a number of sites around Scott Base and McMurdo Station including the cargo loading and unloading areas in the transition zone and at the ice wharf. The method of collection identified and recorded the type and numbers of species present in the soil samples.

The sites selected for soil sampling included the Hilary Field Centre, Cool Store, loading zone at the back entrance, the transition zone, behind the base kitchen, two container storage areas and the Ice Wharf at McMurdo Station as outlined in Figure 3.10.

Figure 3.10 Map of Scott Base showing the location of soil sample sites (▲). Eight sample sites were selected in areas that had high foot and vehicle traffic (map produced by P. Barr).

3.10.1. Use of the core sampling equipment

Four soil core samples were taken from each site using an auger for cores 80mm in length and 48mm in diameter. The intended method of operation was that the steel tube would be attached to the base of the auger and placed on the soil. Using both body weight and a soft faced hammer the tube would be pushed into the soil. The core would then be released by turning the handle half a turn to break the core from the soil and pulled from the ground. The core would then be removed from the base of the auger and the sample dislodged by tapping the side of the auger with a screwdriver.

On the day of data collection the ground at most sites selected was too hard to allow this method to be used and was only effective in locations which were largely ice with little soil content. Soil was in a state of permafrost and therefore extremely difficult to break through. The areas of ice were found to be softer.

Scraping soil samples from the surface to a maximum depth of a few centimetres at each sampling location was employed as an alternative method. Two samples were collected at each site. One sample from each location was immediately frozen and a second sample was allowed to thaw before being examined for seeds.

The examination of the soil samples was conducted by placing the defrosted sample material into a seed tray and searching through the material to identify any seed material. Microscopes were not available for this screening. Following examination, the samples were re-bagged and frozen along with the other samples. The unidentified material was bagged separately, labelled and also frozen. These samples have not yet returned to New Zealand and remain at Scott Base for logistic and financial reasons. The results of the visual inspections are presented in the next chapter.

4. Results

4.1. Shipping containers - seed trays

The seed trays placed on the roof of the shipping containers caught anything likely to lodge on the top of containers in storage at Antarctica New Zealand. This method of seed collection allowed for easy germination as the seed goes directly into the growing medium. Two seed trays acting as a control condition were set up in an area of known high seed fall, to determine the success of this methodology. When the seed trays were transferred to a glasshouse after 4 weeks there was a seedling growing in one of the control trays (Figure 4.5) indicating the method was suitable for capturing seeds.

Once all of the captured seeds had germinated in the glasshouse they were identified visually and the species confirmed by comparison with appropriate references (Roy, 2004). The quantity and types of seeds that germinated are noted in Table 4.1, which shows that 5 plants germinated from 16 trays, of which three were from Group One and two from Group Two.

Table 4.1 The number and type of species that germinated in the seed trays

Group No.	**Container seed trays**	**No. of plants**	**Family name**	**Species name**	**Common names**	**See Figure**
1	1	1	Fabaceae	Trifolium	Clover	Figure 4.1
1	2	0				
1	3	0				
1	4	0				
1	5	1	Fabaceae	Trifolium	Clover	Figure 4.1
1	6	0				
1	7	1	Asteraceae	Taraxacum officinale	Dandelion	Figure 4.2
1	8	0				
2	A	0				
2	B	0				
2	C	0				
2	D	0				
2	E	0				
2	F	1	Malvaceae	Modiola caroliniana	Creeping mallow (juvenile)	Figure 4.3
2	G	1		Poa	Unidentified grass species	Figure 4.4
2	H	0				
	Control X	1	Solanaceae	Petunia	Petunia	Figure 4.5
	Control Y	0				

The quantity of seeds collected was likely to be much greater than the number of plants that germinated. This is due in part to the seeds being given only four weeks in the glasshouse to germinate and partly due to non-viability of some seeds collected via this method. The plants which germinated are described in more detail below.

Figure 4.1 ***Trifolium*** **that grew in trays one and five (Group One) (Photograph by A. Fortune).**

Trifolium, commonly known as clover (Figure 4.1) is a common pasture species found throughout the North and South Islands of New Zealand. It is originally from Europe, North and West Asia and North Africa (Roy, 2004). The area surrounding Antarctica New Zealand is a grassy paddock, so the presence of clover in the seed trays was not unexpected.

Figure 4.2 ***Taraxacum officinale*****, which are common throughout New Zealand, grown in tray 7 (Group One) (Photograph by A. Fortune).**

Originally the *Taraxacum officinale* (Figure 4.2) came from Europe and is now distributed throughout the North, and South Islands, Stewart Island and numerous offshore islands of New Zealand. It is a hardy plant and is found in a variety of habitats, including pasture, roadsides, cultivated land and wastelands (Roy, 2004). Given its abundance in this region it is not unexpected that these seeds were caught in the seed trays.

Figure 4.3 ***Modiola caroliniana*** **found in tray F (Group Two) (Photograph by C. Fortune).**

Modiola caroliniana, more commonly known as the creeping mallow (Figure 4.3) is found in the vicinity of the Christchurch area, Nelson, Marlborough and commonly in the warmer areas of the North Island. Creeping mallow is originally from the tropical areas of America and warm temperate areas of North America (Roy, 2004).

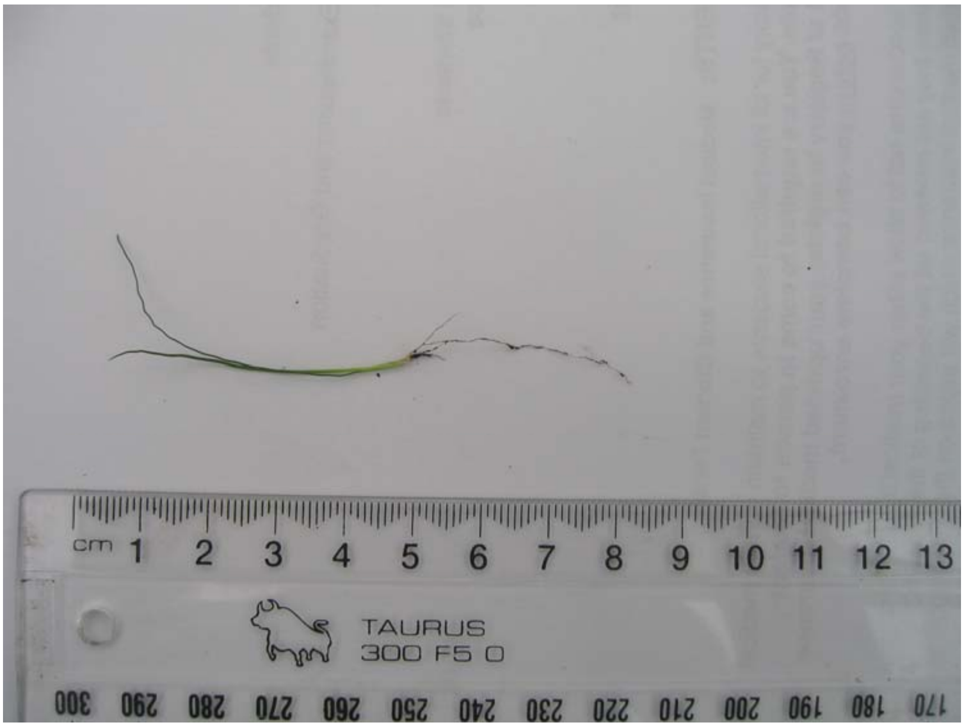


Figure 4.4 An unidentified *Poa* species found in tray G (Group Two) (Photograph by C. Fortune).

Figure 4.4 shows an unidentified grass species which was found in tray G (Group One), and is most likely to have blown in from the surrounding paddocks or grassed areas in the vicinity of Antarctica New Zealand.

Figure 4.5 *Petunia* which grew in control tray X (Control tray) (Photograph by A. Fortune).

Petunia, commonly known as petunia is a common garden plant (Figure 4.5) and grew in Control tray X. It readily grows in the surrounding suburban gardens in Christchurch and its seeds could easily be transported by wind to the area where this tray was located in the grounds of the University of Canterbury.

4.2. Shipping containers - seed traps

Located 0.8m above ground level, these seed traps were found to be effective at trapping both seeds and insects. Although the collection of insects was not the focus of this research, the data have been included as the presence of insects indicates another form of possible biosecurity risk to the Antarctic.

A total of 1,379 seeds and 531 insects were collected across the data collection period. It can be seen in Table 4.2, that the average number of seeds collected in the first round of seed traps (round one, 1/1-14/1) was almost twice as many (n = 67) compared with the later round (round two, 1/2-13/2, n = 34). The number of insects collected in the second round of traps also dropped (n = 16 vs. n = 24), but not as markedly as for seeds. One container (sample 14, round 2) was dropped while being transported, spilling its contents and has been removed from calculations.

Table 4.2 The total number and average number of seeds and insects collected in the seed traps.

	Seeds	Insects
Total Number	1379	531
Average per trap across period	51	20
Average Round One (1/1-14/1)	67	24
Average Round Two (1/2-13/2)	34	16

The results show that there is a significant presence of both seeds and insects in the areas that the containers are being stored and packed. The number of seeds collected in each trap is shown in Figure 4.6 ranging from 17-145 in round one, and 16-84 in round two, and the number of insects collected in each trap is shown in Figure 4.7.

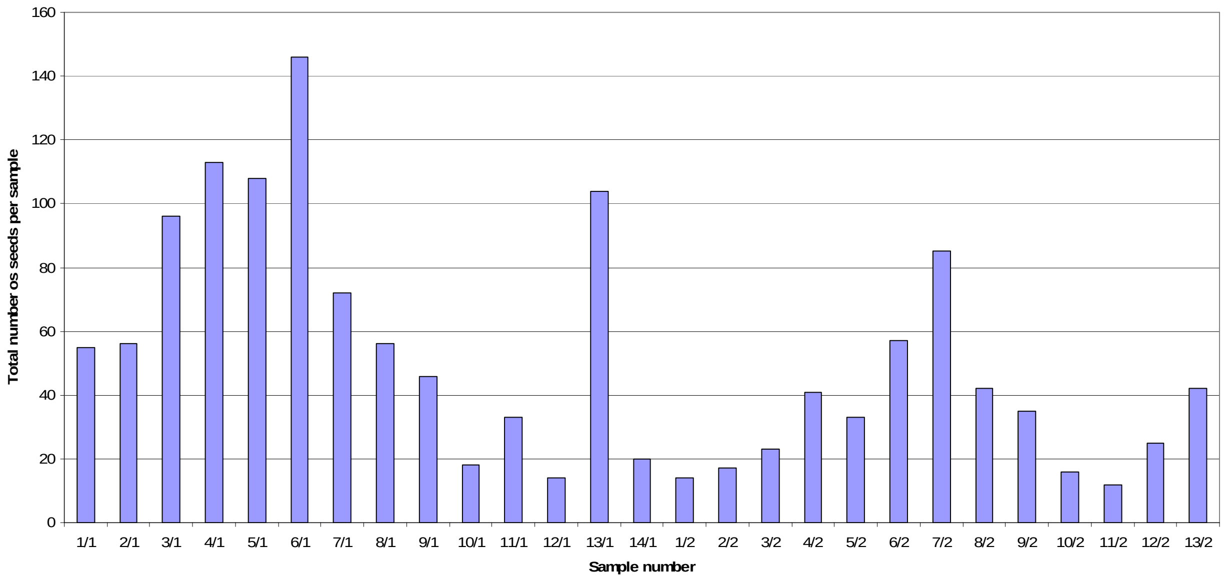


Figure 4.6 Total number of seeds collected per seed trap.

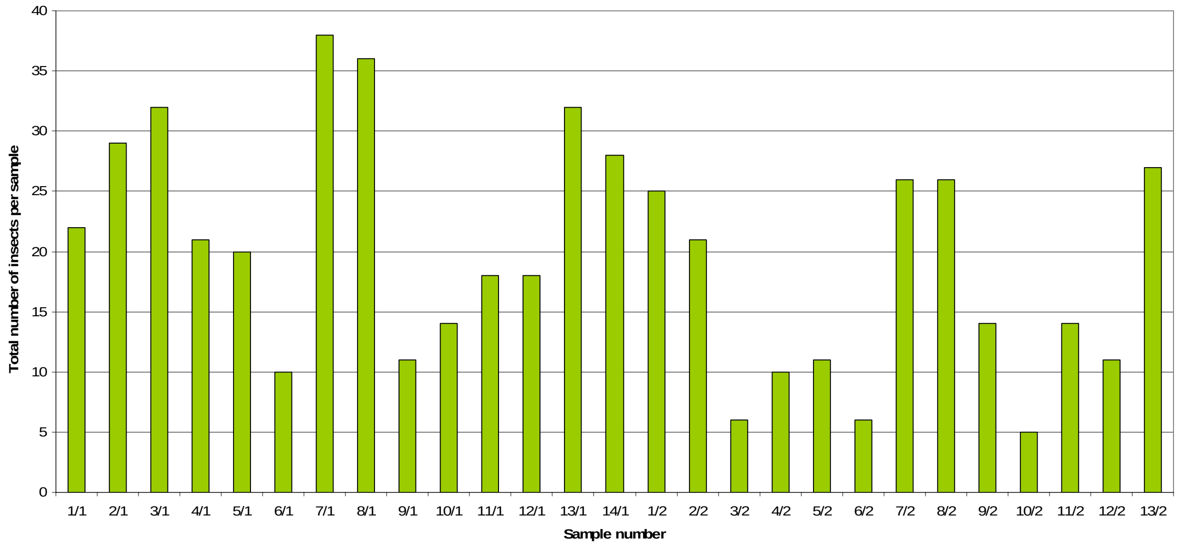


Figure 4.7 Total number of insects collected per seed trap.

This method of trapping insects and seeds is effective in that no soil is required within the collection device, which simplifies the sorting of the seeds and insects later. An advantage is that all types of seeds trapped, whether they are viable or not, can potentially be identified visually, rather than requiring germination. Besides this it is advantageous to be able to account for all seeds that have been trapped whereas in seed trays only those that are viable are accounted for.

4.3. Shipping containers - sticky traps

A total of 46 seeds and 11 insects were collected from the sticky traps after four weeks (Table 4.3). This suggests that wind-borne contaminants in the vicinity of the containers have the potential to become affixed to the shipping containers prior to departing Christchurch. Sticky traps had two faces, A and B. The A sides of both traps faced in the same direction (south), so the higher seed counts on these sides can be attributed to the prevailing wind.

Table 4.3 Shows the data collected from the sticky traps at the end of four-week period December 2005.

Trap Number	Side	Seeds	Insects
Sticky trap one	A	12	2
	B	4	2
Sticky trap two	A	23	2
	B	7	5

Part-way through data collection a temporary fence was erected across the face of sticky trap two. While the fence only blocked a small part of one side of the trap (Figure 4.8), it is uncertain whether any significant interference of the sample occurred.

Figure 4.8 Sticky trap two showing the fence that was unexpectedly placed across the middle of the trap halfway through the data collection period (Photograph by A. Fortune).

4.4. Shipping containers – manual inspections

There were two quite distinct batches of shipping containers in the storage area. Containers being shipped to Antarctica had been painted more recently compared to other containers sitting in the storage area behind Antarctica New Zealand that were less well maintained and had rougher surfaces. The newly painted containers had fewer visible contaminants following wet weather conditions than the older containers. The newly painted containers have a much smoother finish, making it more difficult for contaminants to adhere to the surface.

A total of 277 seeds were located on containers, an average of 21 seeds per container ranging from 1-40 seeds per container as shown in Table 4.4. Container number 1633979 had a number of insects which were found in bird droppings on top of the container.

Table 4.4 Total number of seeds and insects found and weight of material collected per container on the shipping containers at Antarctica New Zealand.

Container identification number	Soil weight (g)	Seeds	Insects
1324727	1.5	18	
2760968	1.8	6	
3008219	1.8	19	
3933595	1.9	5	
1905640	3.5	14	
647110/3	4.9	30	
1401633	5.4	20	
1567270	5.5	28	
2783027	13.5	40	
1633979	35.4	37	6
1800762	104.2	38	
1809097	1172.5	22	
Total	1351.9	277	6
Average		21	

Of the containers examined only 9 seeds were found on the roof (Figure 4.9) including a cluster on container 647110/3 under a piece of wood. However, spider webs played a significant role in capturing contaminants and this was where most seeds were located. These webs were found mostly around the protrusions on the containers, such as the hinges and around the tops of the walls. Other areas of interest were the door hinges and the base plates which collected large volumes of dirt and stones as seen in Figure 4.10.

The history of one of the shipping containers provided an insight into the acquisition of seeds, grasses and rubble/gravel. Container 1800762 was used as part of the ANDRILL project to Cave in South Canterbury region some time prior to being packed to go to Antarctic. ANDRILL[28] is a large international geological drilling programme that is being carried out in the McMurdo Sound area. Drilling trials were undertaken in Canterbury before equipment was shipped to Antarctica. A large number of seeds were found on the container. The outside of the container had not been cleaned prior to packing for the Antarctic. This container also had large amounts of *Dactylis glomerata* (cocksfoot grass) which was seen but not counted as part of the study because it was being packed and it was not safe to collect the samples.

Figure 4.9 Data collection on top of the containers at Antarctica New Zealand (photograph by S. Harris).

A large amount of soil, stone and other contaminants were evident on the containers as shown in Figure 4.10. The weights of the soil material collected varied greatly between containers as shown in Table 4.4 and ranged from 1.5 grams to 1172.5 grams per container. The volume of the material found did not always strongly correlate with the number of seeds contained within it. Container 1809097 had previously been part

[28] www.andrill.org ANDRILL accessed on 05/05/06

of a drilling project in South Canterbury in a gravel area. This container had over ten times the quantity of soil material compared to the next highest container 1800762, which had 104.2 grams of soil.

Figure 4.10 Dirt, stones and other contaminants found on the base plates of containers. This shipping container (1809097) had been in South Canterbury as part of a drilling project (Photograph by A. Fortune).

4.5. Shipping containers - internal inspections

It was intended that as containers were being packed they would be inspected internally in order to identify how much vegetation was inside the container before packing commenced. It would then have been possible to quantify how much vegetation was being unintentionally packed with the cargo. Unfortunately, the containers were packed and shipped in such a short time frame that it was not possible to undertake this examination without interfering with the operations of Antarctica New Zealand and therefore it was not possible.

4.6. Inspection of clothing

Clothing supplied by Antarctica New Zealand prior to departure for Antarctica was examined after the clothing had been cleaned but before it was re-issued to those heading for Antarctica. This was to ascertain how much seed or vegetation remained in the gear.

The total of 335 items was inspected yielding 9 seeds. This means that there is a 2.7% chance of a seed being contained within an item of clothing that is worn to Antarctica. Given that a standard issue set contains 17 items of clothing, with a 2.7% chance per item, this gives a 46% chance of there being a seed within each set of standard issue clothing. Figure 4.11 shows the number of seeds found in each item of clothing. Salopettes had the greatest number (n = 6) of seeds. Three other items each contained 1 seed: a thermal shirt, thermal fleece jacket, and polar fleece headband. As shown in Figure 4.12 the thermal fleece salopettes had the highest average number of seeds per item.

All of the garments sampled, except woollen mitts and gloves, were found to carry other contaminants. The largest volume of organic matter was found on carryall bags. Mostly contaminants were along the straps, particularly on the base where the bags had been placed on the ground, resulting in grass being caught in the strapping material. This was due to the straps being of woven material and the seeds being trapped within the weave. The main contaminants found were pieces of grass and leaves. Sorrels and carryall bags also had mud and dirt on the outsides.

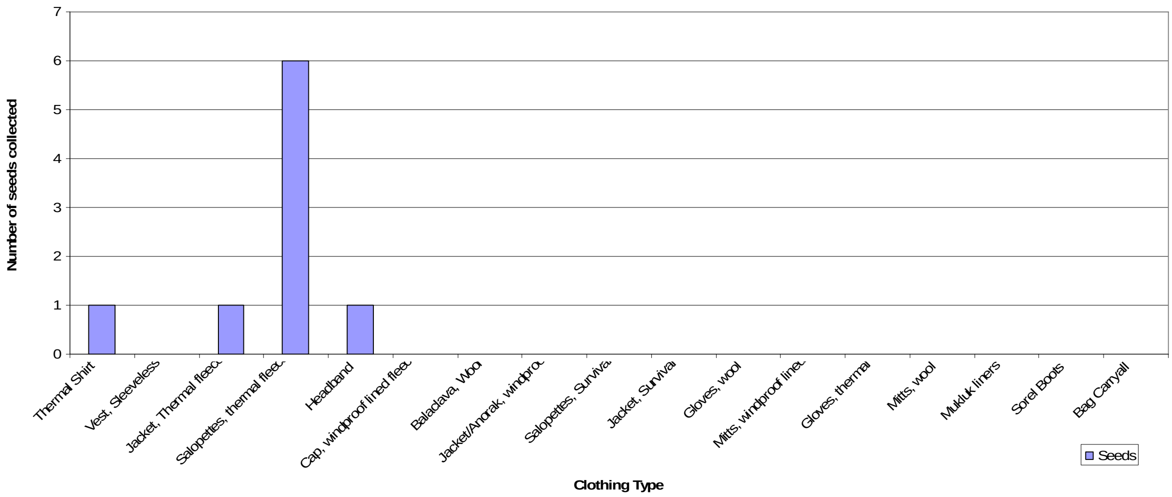


Figure 4.11 Total number of seeds collected for every item of clothing examined.

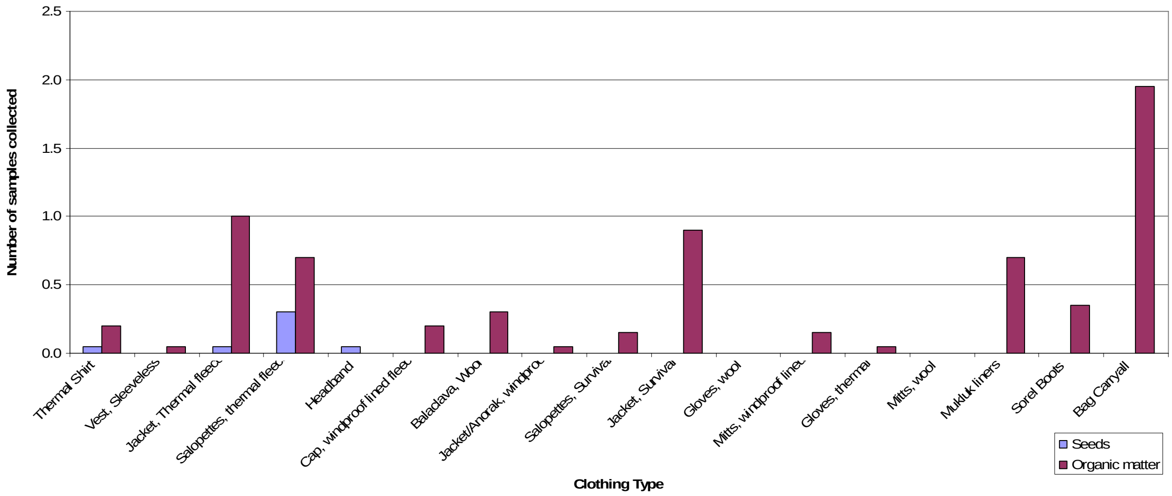


Figure 4.12 Shows the average number of samples of seeds and organic matter collected per item of standard issue clothing.

The area of the garment that contaminants were found can be seen in Table 4.5. Contaminants mainly collected in pockets and lining materials. Large volumes of rock and inorganic rubbish were also found in many of the pockets, most often in the survival jackets and carryall bags.

A key finding of this study is that although some of the clothing was brand new, it still contained seeds and vegetation. Most notably the polar fleece shirts evidenced this, as two out of three new shirts were contaminated.

Table 4.5 The location of seeds and organic matter found in the items of clothing and footwear.

Item	Location
Thermal shirt	All over
Vest, sleeveless	Pockets
Jacket, thermal fleece	Pockets and inside lining
Salopettes, thermal fleece	Inside legs
Headband	Fleece
Cap, windproof lined fleece	Fleece lining
Balaclava, Wool	Within the wool
Jacket/Anorak, windproof	Lining
Salopettes, Survival	Velcro
Jacket, Survival	Pockets
Gloves, wool	-
Mitts, windproof lined	Outside of gloves
Gloves, thermal	Outside of gloves
Mitts, wool	-
Mukluk liners	-
Sorel Boots	Base of the boots
Bag Carryall	Straps and inside the bags

4.7. Airborne pallets of 'freshies'

Due to the nature of the freshies the invasiveness of the inspections was kept to a minimum. As a result, the inspections were largely visual, with only qualitative recordings taken of the extent of contamination. The Ministry of Agriculture and Fisheries (MAF) regulations require a level of cleanliness of the freshies prior to the export of the goods to any overseas destination, including Antarctica. These inspections by MAF are undertaken at Antarctica New Zealand several times per year.

The freshies are usually delivered to Antarctica New Zealand by a local supplier in Christchurch the day before the flight is due to leave for Antarctica. The freshies arrive loaded onto pallets (Figure 4.13), which are then transferred into large wooden aircraft packing crates. They are then loaded onto the planes shortly before departure. It was found that the bottom of the packing crates had noticeable quantities of contaminants, mostly vegetation, dirt and other debris. At the time of packing there was no evidence that any cleaning of the packing crate was being undertaken although this may have been due to the very late arrival of the freshies on the day of the inspection, leaving staff on a very tight schedule.

Figure 4.13 Pallets of 'Freshies' ready for loading onto the aircraft for Scott Base, Antarctica (Photograph by A. Fortune).

The results of the collections of contaminants located on the freshies consignments are tabulated in Table 4.6. The cauliflower and spinach had significant volumes of dirt around the base of the vegetables. The cabbage was not as dirty but had spiders' webs, spiders and insects within the leaves. Most of the fruit produce appeared to have minimal contaminants which may reflect that much of this produce is imported from overseas and therefore had undergone biosecurity checks prior to entering New Zealand.

Table 4.6 Contaminants by type of produce located in fresh produce destined for Antarctica.

Broccoli	**Clean**
Cauliflower	Some dirt around the stem
Cabbage	Spiders, spider webs and insects. Dirt around base
Celery	Clean
Herbs	Clean
Parsley	Clean
Lettuce	Dirt, insects and spiders throughout
Capsicum	Clean
Mushrooms	Large volumes of dirt
Courgettes	Clean
Potatoes	Washed but bagged
Kumara	Washed
Spinach	Some dirt
Silverbeet	Some dirt on the stems
Watermelon	Clean
Melon	Clean
Pineapple	Some mould around the head of the pineapple
Apples	Clean
Apricots	Clean
Nectarines	Clean
Peaches	Clean
Oranges	Clean
Mandarins	Clean

4.7.1. Cargo travelling by air

The intention was to carry out inspections of a sample of the pallets being used to transport equipment by air to Antarctica. However it transpired that equipment is usually packed on the day before, or at least many hours before flights departed. This, combined with a low number of flights, made inspecting these pallets unfeasible.

4.7.2. Aeroplanes

It was also intended that internal and external checks of the RNZAF planes would be conducted prior to departure for Antarctica. However airport security restrictions made this impossible.

4.8. Scott Base – soil samples

4.8.1. Soil sampling

As described in the methods section, two samples were taken from each location, one was thawed and inspected for the presence of seeds, while the other was kept frozen. This material would have been returned to New Zealand subject to funding and MAF clearances, however the results are available and presented below.

Table 4.7 Locations where soil samples were collected at Scott Base showing presence of potential seeds.

Location	Sample Number	Number of Seeds	Status of sample
Road adjacent to McMurdo Ice Wharf	1	0	Sampled & frozen
Road adjacent to McMurdo Ice Wharf	2	Unknown	Kept Frozen
Outside backdoor Scott Base	1	0	Sampled & frozen
Outside backdoor Scott Base	2	Unknown	Kept Frozen
Outside kitchen Scott Base	1	0	Sampled & frozen
Outside kitchen Scott Base	2	Unknown	Kept Frozen
Slip road from Scott Base to sea ice	1	0	Sampled & frozen
Slip road from Scott Base to sea ice	2	Unknown	Kept Frozen
East of the Hillary Field Centre	1	0	Sampled & frozen
East of the Hillary Field Centre	2	Unknown	Kept Frozen
Container storage area Scott Base	1	3	Sampled & frozen
Container storage area Scott Base	2	Unknown	Kept Frozen
Hangar Scott Base	1	1	Sampled & frozen
Hangar Scott Base	2	Unknown	Kept Frozen
Garage Scott Base	1	0	Sampled & frozen
Garage Scott Base	2	Unknown	Kept Frozen

The sampling was conducted on the 21st November 2005 at Scott Base and McMurdo Station ice wharf, Antarctica. The conditions at the time of sampling were -11.5°C, overcast (8/8 stratus) with a south-easterly wind of 5-8 knots.

The examination by eye revealed very little evidence of non-indigenous biotic material within the samples. There was a common presence of wood chips in many samples, which was likely to have come from the construction activities around the site. Two samples revealed possible biotic material that can be seen in the photographs in Figure 4.14 and Figure 4.15.

Without the relevant expertise or the availability of a microscope at Scott Base it is difficult at this stage to confirm that the material identified was vegetation. The samples were not able to be returned to New Zealand for further investigation, as the permits required for biosecurity clearance to bring the material back were too costly.

The difficulty of sampling in the Antarctic can be seen in Figure 4.14 and Figure 4.15. The water content within the samples was extremely high. This meant that when the samples were left to defrost they became very watery. This left little soil material, which made it difficult to identify any potential seeds that were present within the sample.

Figure 4.14 A sample taken at the road in front of garage Scott Base (Photograph by N. Gilbert).

Figure 4.15 shows the sample taken from in front of the hangar at Scott Base (Photograph by N. Gilbert).

There were potentially four non-mineral items found in two of the samples. From the photographs the sample found at the hangar is thought that is more likely to be a wood chip (Figure 4.16), common around Scott Base, due to the construction work in the past.

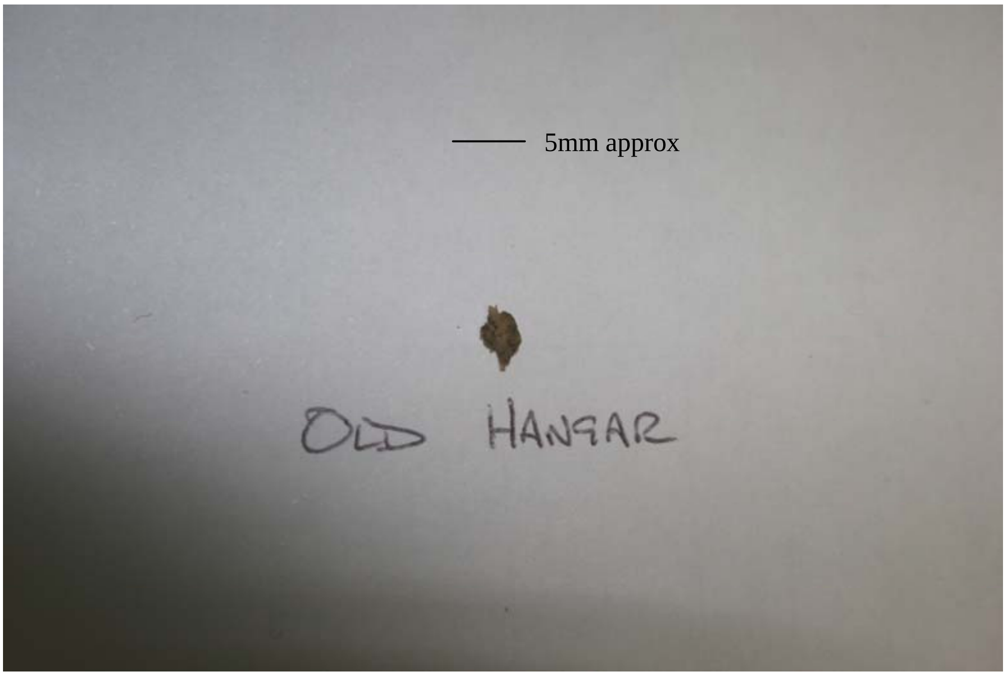


Figure 4.16 Shows possible seed found at the hangar, Scott Base (Photograph by N. Gilbert).

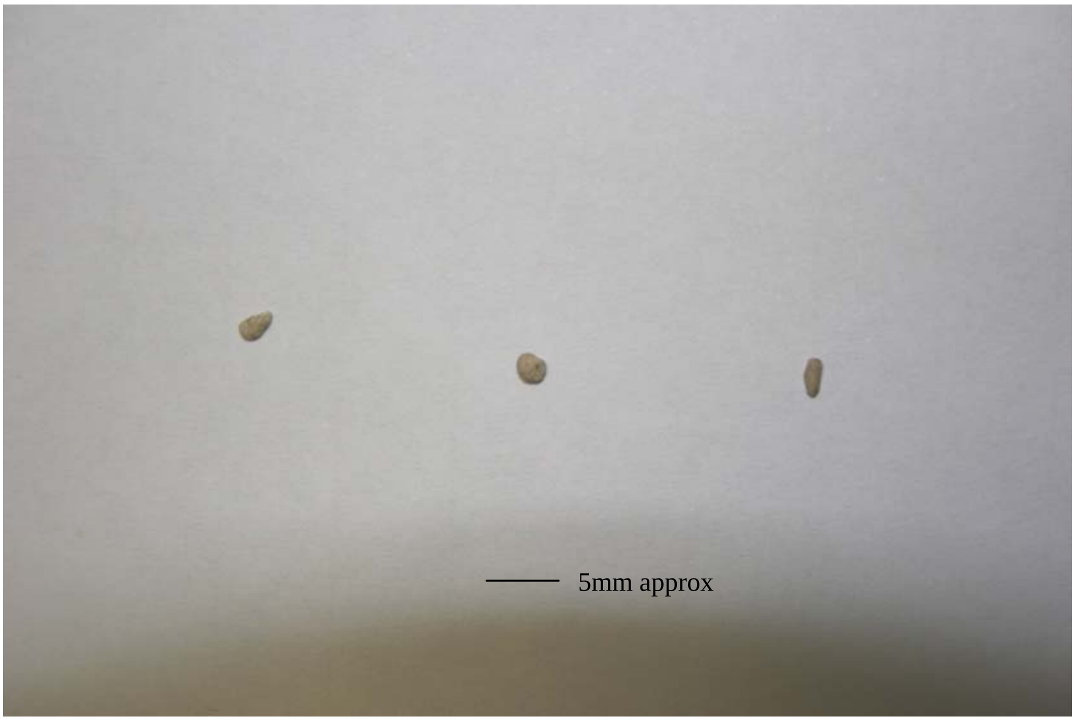


Figure 4.17 Shows three of the non-mineral items that were found at the storage container area at Scott Base (photograph by N. Gilbert).

In Figure 4.17 three potential seeds located at the storage container area at Scott Base can be seen. These three objects look similar to seeds, though this was difficult to determine without the use of a microscope or germination experiments. It is not known whether germination would be successful due to water damage and the extreme temperatures the seeds endured. From Figure 4.17 and other photographs and descriptions supplied by those carrying out the experiment in the Antarctic it was thought that numbers one and three (above) are likely to be seeds but number two was more likely to be other biotic material.

4.8.2. Problems with sampling

It was initially intended to use a soil coring device for removing the soil samples. However the soil coring device was not suitable as the permafrost ground conditions were too solid and it was not possible to extract samples with this tool. This meant that the quantity of soil extracted with each sample was much less than intended.

Sifting through the samples by hand was a lengthy process. It would have been more efficient to use a wet/dry sieve method similar to the method used for sorting the seed trap samples. This method may have been more quantitative and may have assisted in identifying smaller biological material if present in the sample. This sampling method require a large amount of water to rinse through the samples, which was impractical given the limited fresh water resources at Scott Base.

5. Discussion and recommendations

Antarctica possesses a unique climate and environment on which humans have had an impact since exploration of the region began in 1821. In order to protect Antarctica, it is critical that non-indigenous species do not become established. Biosecurity is one of the main mechanisms available to achieve this goal, but internationally there is a lack of research on biosecurity issues as they relate to Antarctica.

5.1. Shipping containers

Shipping containers are stored outdoors by Antarctica New Zealand for up to 12 months prior to their use to transport goods between New Zealand and Antarctica. Four data collection methods were used to detect contaminants in the container storage area. These were seed trays, sticky traps, seed traps, and manual collection by the researcher and assistants in Christchurch, as well as soil samples collected at Scott Base a staff member of Antarctica New Zealand. The large number of seeds and insects captured indicates the presence of a significant number of contaminants in the area surrounding the stored containers. However, although the recordings in all three seed trap methods indicated the presence of seeds in the area this does not necessarily mean seeds are attaching to the containers or being transported to Antarctica.

The manual inspection of the containers yielded a total of 277 seeds and 6 insects. The greatest volume of seeds and insects was found using the seed trap methods. It was anticipated that most contaminants would be caught in the roof gutters of the shipping containers. However, the design of the containers being used to transport goods to Antarctica did not include gutters. The next most likely mechanism for trapping of contaminants was spider webs on the exterior of the containers. It was noted that the heavy rain which occurred just prior to sampling removed a large number of webs and seeds from the containers. Washing the containers by water blasting would have the same effect.

The seed tray experiments indicated that at least some of the seeds being transported by air (wind or bird) onto containers are viable and germinate even within a relatively short period of time. The seeds that germinated in the seed trays were common weeds found throughout New Zealand. Some of these species, such as, *Taraxacum, Trifolium* are fairly common in the Mount Cook area, and *Poa* species are common in many alpine areas of New Zealand (Wilson, 1996). These alpine areas have climates more akin to the Antarctic than the plains of Christchurch. If these species can survive in the alpine regions of New Zealand their presence in these areas suggest they may be able to survive in Antarctica.

New Zealand has a duty under the Antarctica Treaty and the Agreed Measure for the Convention on the Conservation of Antarctic Fauna and Flora (1964) *"…to control the introduction of non-indigenous species of plants and animals into the Antarctica Treaty area..."*. Further research into the survival rates and germination of different species in Antarctic conditions needs to be carried out in order to determine whether there are many species in New Zealand which could possibly survive in the Antarctic. In addition, climate change is predicted to provide warmer temperatures in the Antarctic region with a major impact on the growth of plant and animal species in terrestrial and marine environments (Frenot *et al*., 2005; Walther *et al*., 2002). This change may mean that species previously not viable in the Antarctic may in the future be able to survive in this environment, thereby increasing the importance of current biosecurity measures.

It was not possible to examine the undersides of the containers during this study for safety reasons. However, the underside of the containers come in direct contact with the ground, both at Antarctica New Zealand and Scott Base, but also in the other locations where the containers have been utilized, such as at the ANDRILL testing site at Cave. Therefore the undersides of the containers represent a high risk area for contaminants to lodge. This area is also difficult to clean and gets little attention. Similarly, the interiors of containers are potential vectors. During the preliminary discussions with operations personnel at Antarctica New Zealand to establish this study, it was suggested that *all* containers were swept out prior to packing, although this may sometimes not occur.

5.2. Clothing and footwear

The main contaminants on clothing and footwear identified in this study were grasses, seeds and leaves. The sorrels and carryall bags also contained mud and dirt on the outside. Seed contaminants were generally lodged in pockets and the polar fleece linings of jackets and salopettes. The later finding was unexpected. Based on the AAD studies it was thought that the Velcro on clothing would contain the largest numbers of contaminants. Indeed, the finding of this study contradicts the AAD study. Based on their research the AAD modified their clothing to reduce the amount of Velcro on Antarctic gear. In this study Velcro contained large amounts of feathers, human hair and thread entangled in the barbs, but no seeds.

A key finding of this study is that although some of the clothing examined was brand new, and unused, it still contained seeds and vegetation. This was most notable for the polar fleece shirts. Two out of three new shirts were contaminated. Following a discussion with Antarctica New Zealand staff, it became apparent that the manufacturer of this clothing is located in a large warehouse in an industrial area of Christchurch. In hot weather conditions the large doors of the factory are opened to allow airflow through the building. It is conceivable that the grass seed found on these shirts was blown into the building while these doors were open and became attached to the clothing as it was being manufactured.

This study found that seeds and other contaminants were being trapped in clothing, and are likely to be contained in nearly half of all clothing kits issued to staff bound for Antarctic. Polar fleece was the main material that collected contaminants. However, it is not realistic to suggest that polar fleece be replaced with another material, as it is a lightweight modern fabric that performs well in the Antarctic environment. Most clothing issued to those going to the ice is made from polar fleece. It was noted in this study that woollen clothing contained significantly fewer contaminants. Wool is a more expensive fabric than polar fleece, and it also restricts movement as it is heavier than polar fleece. Although it was used extensively by the early explorers it is not suitable with the modern layering of clothing used in the Antarctic to keep warm.

The carryall bags (Figure 5.1) issued to participants of the programme were found to harbour significant numbers of contaminants. These bags come in three different designs. Two of the designs are made from canvas type material with woven handles and the third design is made of a rubberised material with woven handles. Many of the contaminants located in this study were grass seeds trapped within the woven fabric of the carry handles, which are sewn to the exterior of the bag. Some of the bags had straps that went the entire way around the underside of the bag, while other straps ran only down the sides (Figure 5.1). It was those straps which wrapped right around the bag that were found to contain the greatest number of seeds. These bags are often placed on the ground whether at home, at Antarctica New Zealand or at Scott Base. Having the straps wrapping around the underside of the bag means that when the bag is on the ground the straps are in direct contact with the ground. This gives ample opportunity for the bags to collect contaminants and trap them. The third type of bag had a rubberised coating on the fabric that could be easily wiped clean and seeds had much more difficulty adhering to this surface.

Figure 5.1 Carryall bag issued by Antarctica New Zealand showing external straps (Photograph by A. Fortune).

The issued clothing is usually taken home by participants for them to become familiar with, and to pack their own belongings into the carryall bags. Taking bags and clothing home increases the likelihood of contaminants being introduced into the clothing. It is unusual for members of other Antarctic programmes to be issued clothing which they then take home. This is done by Antarctica New Zealand for logistic reasons, particularly the early morning flight departures, which create significant time pressures on the day of departure. This current system may need to be reconsidered. However, if all those going to Antarctica had to be kitted out on the morning of departure increased personnel and time pressures would be considerable. Many participants also take items of their own clothing to the Antarctic. As many of these people carry out research in other areas of New Zealand and internationally, this increases the risk that contaminants could make their way to the Antarctic on items that individuals have not cleaned sufficiently. Scientific equipment is part of this issue.

5.3. Freshies

The examination of fresh vegetables during this study found that lettuce, mushrooms, cauliflower, cabbage and silverbeet were of most concern as potential vectors of biosecurity risk to Antarctica. Dirt and contaminants are supposed to be removed by the local supplier but there appear to be problems with this arrangement which Antarctica New Zealand staff seem to be aware of. This study found dirt around the stalks of the plants which ought to be removed at Antarctica New Zealand prior to being sent to Antarctica. One suggestion to reduce this problem could be to use pre-washed bags of cut lettuce leaves commonly available in most supermarkets. Another option would be to purchase hydroponic lettuces which are raised in a medium other than soil, and in a more controlled environment that tends to contain fewer contaminants. Both of these approaches would also reduce the amount of cleaning at Scott Base which has the added benefit of conserving time and water in Antarctica.

The amount of soil found on the mushrooms in this study was also of concern. The mushrooms were grown in pasteurised soil. Pasteurised soil is heated to kill off contaminants prior to the addition of the mushroom spores[29] and therefore the threat to the Antarctic may be lower than the soil carried on other produce. However, creating more consistent standards of cleanliness across the freshies would be a desirable strategy.

The cauliflower, cabbage and silverbeet examined in this study were found to be dirty and also contained spiders and other insects. It is recommended that more thorough cleaning be carried out. The crate that the vegetables were loaded into for the flight to the Antarctic was not cleaned before boxes of freshies were packed into it. The bottom of this crate appeared to be littered with noticeable quantities of contaminants, vegetation, dirt and other debris highlighting another source of concern.

5.4. Soil sampling in Antarctica

Soil sampling was undertaken by Antarctica New Zealand staff at a number of sites around Scott Base and McMurdo Station including cargo loading and unloading areas in the transition zone and the ice wharf. The examination of the soil samples was conducted by placing the defrosted sample material into a seed tray and searching through the material to identify any seed material. Microscopes were not available for this screening; however three potential seeds were identified from samples collected at the storage container area at Scott Base. This suggests that seeds have probably already been transported to Antarctica.

There have been previous cases in which species have been introduced to the Antarctic. For example, in December 2002 the hydroponics facility at Scott Base was quarantined due to the accidental importation of *Collembola*, commonly known as springtails, into the unit. It was quarantined again in August 2004 due to a second outbreak of springtails. This second incident was possibly due to inadequate cleaning following the initial outbreak (N. Gilbert, pers. comm., 2005). It is unclear how these insects were introduced into the hydroponics unit. Two possibilities are that it was via a contaminated batch of lettuce, or through the exchange of organic material with

[29] http://www.meadowmushrooms.co.nz/growing.htm accessed on the 15th March 2006

McMurdo Station, which also had springtails during the same season. It is unclear which country introduced the springtails into the McMurdo and Scott Base area. Antarctica New Zealand has never identified the springtail species (N. Gilbert, pers. comm., 2005) and the unit remains closed, which makes it more difficult to trace its origin. Since the outbreak, the hydroponics unit at Scott Base has remained closed for that and other reasons, such as, financial pressures of running a hydroponics unit in the Antarctic (N. Gilbert, pers. comm., 2005). This illustrates the fact that outbreaks of undesirable species can occur, but to date there has been very little information on how it occurred, or how to successfully deal with these biosecurity risks following an initial outbreak or identification. It also indicates that the interaction between Scott Base and McMurdo is significant and could be another mechanism for potential contaminants travelling between McMurdo and Scott Base.

5.5. Legislation which aims to protect Antarctica

Despite the vast array of legislation which exists under the Antarctic Treaty, the current biosecurity policies and practices which relate to biosecurity of the Ross Sea Region are contained in the Agreed Measure for the Convention on the Conservation of Antarctic Fauna and Flora (1964) which states"*…to control the introduction of non-indigenous species of plants and animals into the Antarctica Treaty area...*". It is however up to each country with interests in the region to enforce these regulations, using their home nation's laws where they are deemed appropriate. New Zealand's biosecurity laws do not take into account Antarctica, although the Biosecurity Act (1993) is invoked where necessary. When entering New Zealand from the Antarctic all passengers go through customs as they would if returning from any international destination. It is of concern that border controls do not operate upon arrival in the Antarctic.

The Antarctic Treaty does little to address unintentional introductions to the continent and more needs to be done in this area. Legally it is easier to control intentional introductions than unintentional introduction of non-indigenous species into the Antarctic. In addition, the year-on-year increase of tourist numbers suggests that the activities of IAATO members, and more importantly tourist operators who do not operate within this organisation, need close attention as they may well operate outside any of the legislation considered in this thesis. Therefore it is important to educate and encourage vigilance to prevent the unintentional introduction of species. Research has an important contribution to make in these efforts.

Overall there is little evidence that the legislation that aims to protect the Antarctic is being enforced for biosecurity reasons. This may be due to a lack of resources to address biosecurity, or alternatively due to a lack of demand for legal enforcement of the current biosecurity measures. It is also possible for nations to operate in Antarctica without being party to the Antarctic Treaty or its related protocols. In both New Zealand and Australia, there is a broad array of legislation which is complex and its implementation is up to the Antarctic programmes. These programmes have demonstrated willingness in the past to change their practices on the basis of biosecurity threats identified by research, but this research was conducted some years ago and the knowledge base requires expansion. In addition, New Zealand faces a number of competing demands with regard to managing biosecurity. There has been recent publicity which suggests that MAF is having difficulty complying with legislation in general on the home front. For example, the New Zealand Auditor General Kevin Brady[30] recently highlighted deficits in the management of shipping containers. However, for the organisations involved in border security, the biosecurity of the Antarctic may be less pressing than other more immediate concerns where limited resources are available. Australia is considered to be a leader in biosecurity, so more collaboration on effective ways to implement legislation may be beneficial.

5.6. Conclusions

Antarctica possesses a unique climate and fragile environment. Its indigenous terrestrial, marine, plant and animal species, are vital to the food chain in Antarctica and the Southern Ocean. Currently the biosecurity measures being practiced are not preventing contaminants from reaching the Antarctic. The extremely harsh climate is

[30] http://www.nzherald.co.nz/section/story.cfm?c_id=1&objectid=10383481 MAF's handling of sea containers criticised, accessed on 25/05/06.

currently defending the region against the incursion of non-indigenous species. Should this climate continue to change, the risk of breaches of biosecurity will increase. The results of this study suggest that unwanted species can enter the Antarctic in used clothing and travel bags. New clothing was surprisingly also implicated as a vector for seeds and grasses. Finally, unwanted organisms were found on shipping containers, and soil, spiders, and other insects were located amongst fresh produce bound for Scott Base.

Seeds, insects and organic contaminants are the three main biosecurity threats for introducing non-indigenous species to the Ross Sea Region. The main vectors for introducing non-indigenous species to the Antarctic from New Zealand are by plane, ship (Tavares & De Melo, 2004), clothing and footwear (Frenot et al., 2005) in addition to natural pathways such as marine invasions At a macroscopic level the large seeds and insects that were identified in this study at Antarctica New Zealand, combined with the presence of seeds in soil samples in Antarctica, suggest that a real threat to biosecurity exists. In addition, if these results are extrapolated, microscopic species might also pose a significant threat to the Antarctic environment.

5.7. Recommendations

Current biosecurity practices are inadequate in that seeds are present on the containers, clothing and carry bags bound for Antarctica. Seeds do make the transition as evidenced by their presence in Antarctic soil samples. Improved biosecurity in the region could be achieved with the following changes:

- An improved container tracking system including information on where containers have been and for how long could give an indication of the risk associated with each container. This would not be too difficult as the number of containers travelling from Antarctica New Zealand is relatively small.
- Containers need to be elevated using a suitable container hoist for the underside to be washed or brushed. Purchasing equipment such as a container hoist, for such limited use throughout the year may be expensive but worth considering. Alternatively hiring a container hoist for the short loading period might be possible.

- Any containers replaced due to damage or old age should continue to be those with a gutter-free design.
- Containers that are being sent by ship need to be sprayed or washed externally and internally, or at the least need to be swept out before packing and transportation. Cargo being transported by plane also needs to be treated in a similar manner.
- Thorough cleaning and inspection of the clothing would reduce unwanted material being unwittingly transported to the area.
- Polar fleece garments require more than a simple machine wash. They could be visually checked and have any seeds removed by hand. This is a more time consuming method of removal of unwanted material.
- The soles of boots and the sorrels, which are commonly worn around the base and areas of dirt, need to have a more thorough washing to ensure that all dirt is removed, therefore reducing the risk of contamination.
- The canvas material of bags as seen in Figure 5.1 should be phased out and the rubberised type material be used in its place. The handles of the bags also need to be modified in order to minimise the entanglement of seeds. It is suggested that the handles are made of leather or another non-woven material. It would not be suitable to place the handles on the inside of the bags as although it would prevent them being in contact with the ground, it would reduce the strength of the handle (S. Harris, pers. comm., March 2006). Given the loads these bags carry this would likely lead to increased breakages.
- Scientific equipment which has been used around New Zealand and other countries prior to heading for Antarctica is another possible vector that would be able to introduce non-indigenous species to Antarctica. Equipment is randomly checked for cleanliness, but only if the items are suspected to be unclean. It is suggested that more rigorous inspections of the equipment are carried out.
- Freshies need more careful preparation before leaving Christchurch to eliminate soil and insects. The cleaning of the crate is advisable before the boxes are packed to reduce the risk of contaminants being transported to the Antarctic.

- Education is an essential tool for encouraging those involved with Antarctic research to be more vigilant and proactive. The findings of this study could be distributed to Antarctica New Zealand staff to help raise awareness of these potential vectors and threats to biosecurity. An AAD staff education programme greatly reduced the amount of soil, insects and plant material found in cargo. An educational programme to alert members of their Antarctic Programme about the potential impact these non-indigenous species might have on the fragile environment of Antarctica was also implemented in Australia.

5.8. Limitations of this study and recommended modifications for future research

This study was ambitious and I experienced several difficulties which limit the extent to which these findings can be considered robust. The research was difficult to carry out from a health and safety view point because of the movement of freight and vehicles associated with the packing. Packing was happening at the same time as I was attempting to collect data. It was also difficult to trace the whereabouts of the specific containers being sent to Antarctica prior to the packing being initiated.

The sampling at Scott Base went reasonably well, but the sorting of the samples at Scott Base required a sieve, which was impractical due to tight water restrictions. The ground was solid and almost impossible to break through using the auger as originally intended. The original method was only used for the samples at the McMurdo ice wharf and outside the cool store (hanger), where the ground was mostly ice and softer than the frozen earth. The remainder of the samples were scraped or dug out with any tools available. This meant that the sample size varied greatly between specimens and ice was frozen the whole way through the samples. As my proposal was not successful in the scholarship round, I was unable to travel to the Antarctic, therefore, the research at Scott Base was carried out by a third party, which made it slightly more difficult to control the finer details of the sampling process. As yet the samples are unable to be bought back to New Zealand due to MAF restrictions and the inability to obtain a permit for the samples to enter New Zealand. They were therefore examined on the spot and the findings relayed to Christchurch for inclusion.

The New Zealand based data collection was impeded by the fact that the drains of the seed trap containers did not work as well as expected; the mesh was too fine, became blocked by debris, causing the water in the traps to stagnate. Possible solutions are to use different sized mesh or clear the traps following rain to reduce the risk of damage to seeds. It was difficult to get the samples separated from the dirt and several different techniques were used before a successful one was found. The most efficient method given the tools and time available was found to be that of sorting the samples in trays. It was not possible to germinate the seeds from these samples due the water damage that the seeds sustained due to the blocked drains. I was unable to complete data collection on the aircraft as originally intended due to access restriction. This study could be replicated in the future focusing on aircraft and ships as potential biosecurity hazards, this would also allow the generalising of the findings of this study to be explored. Research into the transporting of micro-organisms and/or spores associated with soil importations would provide an assessment of the risk associated with soil carried on the freshies. An audit of tourist operators against the IAATO guidelines would be another area for future research.

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