THE IMPORTANCE OF INTEGRATING SCIENCE AND MANAGEMENT: LESSONS FROM TERRESTRIAL VEGETATION CHANGE ON MACQUARIE AND HEARD ISLANDS

by J. B. Kirkpatrick

(with one plate)

Kirkpatrick, J.B. 2009 (11:xii): The importance of integrating science and management: lessons from terrestrial vegetation change on Macquarie and Heard islands. *Papers and Proceedings of the Royal Society of Tasmania* 143(1): 25–32.
https://doi.org/10.26749/rstpp.143.1.25 ISSN 0080-4703. School of Geography and Environmental Studies, University of Tasmania, Private Bag 78, Hobart, Tasmania 7001, Australia. Email: J.Kirkpatrick@utas.edu.au

Scientific observations have demonstrated massive changes in tall tussock and megaherb cover on Macquarie Island, substantial colonisation of bare ground by native vegetation on Heard Island, expansion of the range of *Poa annua* on Heard Island, and local changes in vegetation associated with changes in the locations of animal aggregations. Suggested recent declines in *Sphagnum* and *Azorella* on Macquarie Island may have occurred but are yet to be proven. Climate change seems certain to have been responsible for vegetation expansion on Heard Island, but its role on Macquarie Island is less clear. The role of variation in rabbit populations on Macquarie Island in causing changes in the areas of vegetation dominated by tall tussocks and megaherbs is scientifically well-established. However, the relative contribution of variation in cat populations, variation in the effectiveness of the *Myxoma* virus and climate change on variation in rabbit populations has been the subject of unresolvable differences in scientific opinion. While science has been generally productive in determining needs for vegetation management and its appropriate course when needed, the bureaucratic separation of managers and scientists within Tasmania, and an emphasis on peer review and strategic research within the Australian Antarctic Division, have contributed to some fracturing of management-related science in the twenty-first century, and have resulted in scientific publication and publicity that has criticised, rather than supported, appropriate conservation management. Long-term involvement of individual scientists in both research and management planning seems to have been a key driver of good nature conservation. A renewed focus on the integration of science and management is recommended.
Key Words: bioturbation, cats, climate change, exotic plant invasion, Heard Island, management, Macquarie Island, myxomatosis, rabbits, science, vegetation change.

INTRODUCTION

Most of the claimants of Antarctic territories have undisputed ownership of at least one of the sub-Antarctic islands. The scientific programs they use to reinforce their claims on Antarctica can have a strong sub-Antarctic component, as in the case of Australia. Although future access to resources is likely to be the main underlying reason for the existence of the current extremely expensive research programs, the public rationale is based on science, in particular, science directed to improving management for nature conservation and sustainability at all of the local, regional and global scales (Frenot 2007).

Several of the sub-Antarctic islands are on the World Heritage List because of their natural values (Jackson 2007), and all are now managed primarily for nature conservation, with some, such as Macquarie Island, also attracting tourism operations (Landau 2007).

The present paper uses the two largest Australian sub-Antarctic islands, Heard and Macquarie, to explore the relationships between scientific research and nature conservation management. Macquarie Island is currently among the most human-disturbed of the sub-Antarctic islands, while Heard Island is among the least modified by direct human activity. Both have World Heritage status. The discussion is concentrated on change in the scientifically best-known element of terrestrial ecosystems, the vegetation.

VEGETATION CONSERVATION AND SCIENCE

The sub-Antarctic islands would seem, on the surface, to be ideal places to maintain or restore natural vegetation. They had no indigenous people, their history of human interference is measured in decades, rather than millennia, and most of the native components of their vegetation are well-known. However, the scientific explorers arrived after the sealers and whalers, making an understanding of the pre-human vegetation cover more difficult than it otherwise could have been. Also, the vegetation of today is part of a sub-Antarctic ecosystem with characteristics that differ markedly from the pre-human condition. Climates are different, introduced species of plants intermix with natives, and the fauna that utilises the islands is different in composition and relative abundance from the pre-human fauna.

Kirkpatrick & Kiernan (2006) have argued that nature conservation management of any reserve should concentrate on the elements of biodiversity and geodiversity that are most dependent on that reserve. This approach values the maintenance of variety in nature on the planet as a whole, not just in the area of interest. It differs from the more widely adopted approach, which is to use management to try to achieve a state which more closely resembles the pre-human condition.

Scientific research can be idiographic, concerned with describing nature, or nomothetic, concerned with testing hypotheses of causation. The first approach is inductive, the second deductive. Both types of science can provide important information for the conservation management of vegetation.

Idiographic research determines what is what, how these "whats" vary through space, how whats vary through time and the relationships between the various whats. Management responses should be considered when idiographic research indicates that a potentially deleterious change is underway. Also, the priorities for management may change as a result of idiographic research. For example, the research that resulted in the declaration of *Azorella macquariensis* Orch. as a Macquarie Island endemic makes it legally a more important taxon to sustain than in its previous manifestation as the circumaustral *A. selago* Hook.f.

To work out whether a management response to a potentially deleterious change is possible, and, if possible, which approach is likely to be the most effective, it helps if causation is understood. The nomothetic approach does not pretend to be able to determine the absolute truth of causation, but can be highly effective in eliminating potential causes, sometimes leaving but one hypothesis. In practice, much research integrates both approaches. Hypotheses and models often arise from inductive scientific observations and can be unintentionally invalidated by idiographic work.

The results of scientific research vary in their certainty, which is rarely, if ever, total. The study of vegetation change is no exception to this general rule of variation in certainty. There are substantial observation errors associated with all forms of data used for change detection. The sampling strategy, if any, can strongly influence confidence in results, as can the coverage of time and space. Vegetation can change cyclically or chaotically as well as directionally, and cycles can vary in periodicity.

The different techniques for obtaining vegetation change data vary in their discriminatory powers and their potential for spatial and temporal coverage. The longest temporal cover can be obtained from deposits of pollen and macrofossils in their sedimentary context. Historical descriptions, oblique photographs and paintings, vertical aerial photographs, satellite digital data and permanent plots can provide data for temporal analysis of vegetation change. Wide spatial coverage can be easily obtained from satellite digital data, although, in the sub-Antarctic, persistent cloud cover makes their useful temporal incidence extremely sporadic. Vertical aerial photographs have been rare on the Australian sub-Antarctic islands for the same reason, and because there have been very few flights over them. Early oblique photographs were taken for other reasons than monitoring of vegetation change until the late decades of the twentieth century, so have poor spatial coverage before the mid-twentieth century. Similarly, permanent plots are a recent development, as well as being highly labour intensive. In an environment where organic material readily accumulates, macrofossils have potentially good spatial cover, but the labour input has mitigated against their widespread use.

VEGETATION CHANGE

The vegetation pre-1900

Holocene pollen and macrofossil sequences have been analysed from several locations on Macquarie Island (Selkirk *et al.* 1983, Bergstrom 1986, Selkirk *et al.* 1988). These indicate no major changes in the flora or vegetation cover throughout the Holocene until humans arrived on the island in 1810, and do not indicate any great impact after this date, possibly because the sites were located well within the tall tussock and megaherb vegetation of the coastal slopes. In contrast, diatom and sediment data from an inland lake indicate sharp environmental change associated with the arrival of human beings (Saunders 2008).

Our only accounts of the vegetation of Macquarie Island in the nineteenth century post-date European Rabbit, *Oryctolagus cuniculus* (Linnaeus, 1758), introduction, which is reputed to have occurred in 1878 (Cumpston 1968). J.H. Scott (1882) noted swarms of rabbits feeding on the fleshy roots of *Pleurophyllum hookeri* Buchan. at the northern end of the island during his visit in late 1880. At this very early stage of rabbit invasion he described the vegetation of the island viewed from the sea: "... what vegetation there is has a great deal of sameness, long stretches of yellowish tussock, with occasional great patches of the bright green *Stilbocarpa polaris*, or of the peculiar sage-green *Pleurophyllum*. These with the rich brown mosses near the hill-tops are all that strike the eye ..." (J.H. Scott 1882, pp. 486–487).

More than a decade later, Hamilton (1894, p. 584) described an altitudinal transect from Lusitania Bay: "Immediately behind ... the sloping terrace [was] covered with a huge tussock grass. This grass [*Poa foliosa*] forms a huge stool, behind which there is usually a muddy pool ... Once beyond the belt of swamp ... you struggle and wrestle with the huge leaves of the Macquarie Island cabbage [*Stilbocarpa polaris*] ... The tussocks and the *Stilbocarpa* become smaller as you ascend, and at about 300 ft you gain a plateau so swept by the antarctic gales that vegetation is reduced to compact closely-growing mosses, small Uncinias, and the conspicuous cushion-like masses of *Azorella selago*. ... Round the tops of the hills the wind has cut out wonderful terraces from a few inches to a foot or two in height, with completely bare rock much disintegrated by the weather on the top. In some of the more sheltered places or gullies stunted plants of *Stilbocarpa* and *Pleurophyllum* cover the ground." This description does not seem consistent with the types of rabbit damage recorded by later observers, so may also act as an indicator of the pre-human vegetation patterns on Macquarie Island.

There are no published fossil plant data from Heard Island, nor any nineteenth-century vegetation descriptions. However, the present vegetation is among the most "natural" on the planet, with only one known alien plant species, *Poa annua* L. (J.J. Scott 1989, Scott & Bergstrom 2006).

Changes in tall tussock and megaherb cover

Taylor (1955) observed a rabbit grazing front on Macquarie Island, where the rabbits "strip a small area completely before moving on" (p. 96), leaving some patches totally ungrazed. The grazing occurred on the steep coastal slopes, where Taylor (1955) observed and photographed what he thought were grazing-induced land slips. There is little doubt that the rabbits had been moving around the island, with the tall tussock and megaherb vegetation at least partially recovering its structure between grazing events (Sobey *et al.* 1973, J.J. Scott 1988). For example, Taylor (1955) believed that the rabbits had not reached the northern end of the island, where J.H. Scott (1882) had observed "swarms" eating *Pleurophyllum* in 1880. Taylor (1955) and Costin & Moore (1960) were pessimistic about the future of the vegetation of the island with continued rabbit grazing, given their observations of putatively rabbit-induced mortality of tall grass tussocks and megaherbs. They had no temporal data apart from a few photographs taken during earlier expeditions, such as the 1911–14 Australasian Antarctic Expedition (Mawson 1943), so relied on substituting space for time in coming to this dire conclusion.

The decline of megaherbs and tussocks reversed in the 1980s and 1990s coincident with a marked decline in rabbit populations after the effective introduction of *Myxoma*, the reversal being well-documented by data from permanent plots (Copson & Whinam 1998, Scott & Kirkpatrick 2008). By 2003, tall tussocks and megaherbs were again in decline (Scott & Kirkpatrick 2008). By 2007, they were dead or decrepit over much of the island (Carmichael 2007, Scott & Kirkpatrick 2008, Bergstrom *et al.* 2009), a reliable conclusion based on repeat photography, satellite remote sensing and some permanent plot data. The possible causes of this latter decline are discussed in the next section.

Changes in megaherb and tall tussock cover have also been observed in places where animal populations were known, or thought, to have changed, or human settlement abandoned. Devegetation, and intertussock erosion of *Poa foliosa* (Hook.f.) Hook.f. grassland, at Bauer Bay was suggested by Taylor (1955) to probably be associated with an increase in numbers of Southern Elephant Seals *Mirounga leonina* (Linnaeus, 1758), since 1922. A large King Penguin, *Aptenodytes patagonicus* J.F. Miller, 1778, rookery on the Isthmus was exterminated by the sealers in the middle of the nineteenth century (Mawson 1943), with no signs of it in the tussock vegetation in photographs taken in 1911 (Taylor 1955). Some of this vegetation was destroyed by the establishment of the ANARE Scientific Station in 1948. The vegetation at the sealing settlements (1810–1922) on Macquarie Island had recovered by 1951, except for a concentration of the introduced herb, *Stellaria media* (L.) Cyrillo (Taylor 1955). On Heard Island, the abandoned ANARE station was partially colonised by megaherbs (Whinam *et al.* 2004)

Most communities, including some with tussock (*Poa cookii* (Hook.f) Hook.f.) and the megaherb *Pringlea antiscorbutica* T.Anderson ex Hook.f., expanded their areas on Heard Island between 1947 and 2003 (J.J. Scott 1990, Scott & Bergstrom 2006). Changes in the area of vegetation cover are apparent from sequential remote sensing images, large numbers of repeated oblique photographs and some repeat sampling of vegetation at relocatable plots (J.J. Scott 1989, 1990).

Invasion by alien plants

The introduced plant species *Cerastium fontanum* Baumg., *Stellaria media* and *Poa annua* have long been established on Macquarie Island (Taylor 1955), with *P. annua* being the only known exotic plant on Heard Island (Scott & Kirkpatrick 2005). The exotics are widespread in disturbed areas below the fjaeldmark zone on Macquarie Island. *Poa annua* extended its range on Heard Island between 1987 and 2004 (Scott & Kirkpatrick 2005, J.J. Scott pers. comm.). The circum-Antarctic species *Leptinella plumosa* Hook.f. was collected for the first time on Heard Island in the 2003/2004 summer (Turner *et al.* 2006). It is impossible to tell how long it had been present on the island, as absence is harder to prove than presence, especially where botanical exploration has been very limited. However, the balance of the evidence suggests recent introduction by seabirds (Turner *et al.* 2006). Seabirds may have also been responsible for introducing *P. annua* to Heard Island (Scott & Kirkpatrick 2005).

Other vegetation changes on Macquarie Island

The waning, waxing and waning of tall tussock and megaherb cover on Macquarie Island has had implications for associated species of lesser stature, well-documented in the literature (Taylor 1955, Copson & Whinam 1998, Kirkpatrick & Scott 2002, Scott & Kirkpatrick 2008, Bergstrom *et al.* 2009). Recent changes in *Sphagnum* and *Azorella* cover have been suggested to have also occurred on Macquarie Island.

Whinam & Copson (2006) presented evidence that they interpreted to show that *Sphagnum* had suffered a recent decline on Macquarie Island. They observed the size and number of patches of *Sphagnum falcatulum* Besch. in November 1992, November 1996, November 1998, November 1999 and March 2004. They used 23 patches, 16 of which were measured in November 1992 and one of which was not measured until November 1998. It is possible to calculate mean annual percentage loss of number of patches between measurement dates from the data in their Table 1. This rate was 7.81% between 1992 and 1996, 5.88% between 1996 and 1998, 18.75% between 1998 and 1999, and 4.97% between November 1999 and March 2004. However, between 1998 and 1999 one patch that had previously disappeared returned out of seven that could have returned (14.28% per annum), with two patches out of nine (5.23% per annum) doing the same between November 1999 and March 2004. Because of this dynamism in a context in which the measurements were of selected patches, not of all patches within areas, it is difficult to tell from the data to what degree *Sphagnum* patches on the island were increasing or decreasing in number and/or size between measurement times, although the higher annual rate of return than loss between 1999 and 2004 appears more consistent with an increase in this period than the posited decrease.

The 1992 and 1996 repeat photographs (figs 2 and 3 in Whinam & Copson 2006) conclusively show an increase in number and size of *Sphagnum* patches at Green Gorge. It may be possible to use later repeat photographs to come to firm conclusions on the temporal patterns of change in this vegetation type, but these probably would need to be annual given the large variations in the magnitude of changes in numbers of patches summarised above.

During the 2008/2009 summer, scientists and managers observed widespread dieback in *Azorella macquariensis*, with those on repeat visits having the strong impression that this was a new phenomenon (J.J. Scott, pers. comm.). However, there have been some previous observations of dieback in the species. Taylor (1955) observed rabbits digging conspicuous "squats" in *Azorella* cushions. The genus *Azorella* is also known to be eaten by rabbits (Chapuis *et al.* 2004). Taylor also noted that *Azorella* leaves died back in patches in March and April, regarding the phenomenon as an aspect of their phenology (Taylor 1955). Repeat oblique photography might give some insights into the novelty of this dieback, if enough old photographs exist and the scenes can be relocated. Mapping the dieback and determining its environmental correlates would be an important first step in determining the cause and the need and potential for management of the phenomenon. Care needs to be taken in attributing dieback to putatively pathogenic organisms on the basis of their association with dieback, as association cannot separate cause and consequence.

CAUSES OF VEGETATION CHANGE

Influences of native and introduced vertebrates

The large populations of nesting, moulting and resting native vertebrates that use both islands fertilise, defoliate and create landforms in the places they use. Changes in populations, or the locations of populations, can be clearly associated with vegetation changes, as in the examples given above. On Heard Island, the expansion of *Poa annua* was statistically associated with moulting and resting animals (Scott & Kirkpatrick 2005).

In itself, the contrast between the vegetation inside and outside the numerous rabbit exclosure plots on Macquarie Island (pl. 1) leaves no reasonable doubt that variations in the intensity of rabbit grazing have been the cause of changes in the cover of tall tussocks and megaherbs on Macquarie Island, and, therefore, of changes in the cover and abundance of taxa of lesser stature. However, the causes of variation in rabbit populations have been disputed.

The evidence for the initial effectiveness of the rabbit control program using the *Myxoma* virus and the rabbit flea is overwhelming (Copson *et al.* 1981, Brothers *et al.* 1982, Brothers & Copson 1988). The dispute relates to the relative contribution of possible causes of the resurgence of rabbit populations in the early twenty-first century. Bergstrom *et al.* (2009, p. 78) stated that: "Rabbit numbers have returned to pre-control levels and this can be clearly ascribed to the removal of cats", although they also stated that: "Higher autumn temperatures may have improved rabbit kitten survivorship up to the winter months'" (Bergstrom *et al.* 2009, p. 79). They dismiss "... some speculation of reduced efficacy of the (*Myxoma*) virus" by Scott & Kirkpatrick (2008) on the grounds that: "... the impact of the *Myxoma* virus was still evident in April 2007, with numerous rabbit carcasses present at the base of coastal slopes ..." (Bergstrom *et al.* 2009, p. 79). Brothers & Bone (2008, p. 143) had earlier expressed a very different opinion: "Ongoing control [of rabbits] was compromised by the failure to ensure supplies of *Myxoma* virus to maintain an effective inoculation program. Any perception that cat eradication was somehow a catalyst for the rabbit population increase that subsequently occurred is erroneous and most convincingly disputed by the historical trends in rabbit abundance on the island irrespective of cat numbers through that time (Copson *et al.* 1981, Copson

PLATE 1
An exclosure on Macquarie Island established by Geof Copson in 1975 (Copson & Whinam 1998). The photo was taken in 2009, after the rabbit population explosion of the early twenty-first century. Stilbocarpa polaris *(Hombr. & Jacquinot ex Hook.f.) A. Gray dominates within the exclosure, but is absent outside (photograph: J.J. Scott).*

2004). Cat predation on rabbits has never been sufficient to regulate rabbit numbers, which is not surprising considering that there were only ever known to be approximately 250 cats on the island (Brothers *et al.* 1985)."

The models on which the conclusion of Bergstrom *et al.* (2009) was based treated cats as a qualitative variable, despite the fact that numbers plummeted to zero between 1998 and 2001 in the course of the extermination campaign, and ignored the evidence of reduced efficacy of the *Myxoma* control program, treating *Myxoma* as a constant. The use-by date of the last of the *Myxoma* vials (2002) is a better fit to the rabbit resurgence than the death of the last cat (2001), even if one were prepared to ignore the pre-*Myxoma* history of the interaction between rabbits and cats, which one logically should not. The fact that cats were on Macquarie island 60 years before rabbits, and the subsequent co-existence of both cats and rabbits, suggests that cat predation alone could not keep the population of rabbits down to a level equivalent to that of the 1980s and 1990s, during which *Myxoma* use was at its height and the rabbit population was comparatively reduced. However, some contribution of cat extermination to the rabbit population explosion may have occurred (Carmichael 2007, Scott & Kirkpatrick 2008). The data available simply do not allow a disentanglement of the contributions of potential causes of the recent explosion in rabbit numbers.

The activities of *Homo sapiens* can cause defoliation, either extreme, as in the case of the construction of scientific stations, or mild, as in the case of trampling damage (Scott & Kirkpatrick 1994). The major future impacts of *H. sapiens* on the vegetation of the two islands are likely to be through unintentional introduction of exotic organisms, the ecosystem effects of the exploitation of marine species in the Southern Ocean and the global effects of air pollution caused by humans on climate (Whinam *et al.* 2005, Whinam *et al.* 2006, Bergstrom & Selkirk 2007).

Climate change

Although the climatic data for Heard Island are inferior to those available for Macquarie Island, the effects of climate change on vegetation change are much more verifiable. Annual average temperature at Atlas Cove on Heard Island was approximately 1°C higher in the period 1997–2001 than between 1948 and 1954 (Thost & Allison 2006). Glaciers reduced in area on Heard Island from c. 290 km^2 to c. 260 km^2 between the early 1940s and the late 1980s (Ruddell 2006) and have continued to recede, presenting new land for the colonisation of plants, an opportunity that has been taken, at least between 1987 and 2004 (Scott & Kirkpatrick 2005, Scott & Bergstrom 2006).

On Macquarie Island, temperatures increased by approximately 1°C between the 1940s and the late 1970s, but have remained stable since (Pendlebury & Barnes-Keoghan 2007), during a period in which annual rainfall and the number of days with rainfall greater than 6 mm showed a tendency to increase (Brothers & Bone 2008). The figure of 6 mm is significant because it is a possible threshold for burrow flooding, which certainly occurs when this amount of rain occurs two days in a row (Brothers & Bone 2008). Heavy rainfalls are also associated with land slips (Selkirk 1996). Brothers & Bone (2008) suggested that rabbits may have relocated their burrows from their previous locations on more gently sloping land to the better-drained tall tussock-covered slopes in response to more frequent burrow flooding events and that, in the absence of effective control through myxomatosis, increased populations had defoliated these areas. They refer to Tasmanian Parks and Wildlife Service unpublished records to reject alternative hypotheses of increased immunity to the disease and a prolonged breeding season related to drier winters.

If some relocation of rabbit burrows to the tall tussock-covered slopes occurred between 1981 and 1995 when rabbit numbers were very low overall, there could have been grazing-related minor thinning of tall tussocks and consequent increases in plant species richness. These changes occurred on apparently ungrazed plots on the slopes in this period and were attributed to endogenous processes (Kirkpatrick & Scott 2002).

Drier conditions resulting from stronger winds have been suggested as the cause of the putative loss of *Sphagnum*-dominated vegetation on Macquarie Island since 1996 (Whinam & Copson 2006). However, the contradiction between the rainfall record and supposed drying has yet to be satisfactorily resolved. One area that may merit investigation is the role of tall tussocks and megaherbs in fog drip. Their destruction by rabbits could have resulted in less moisture reaching the soil. In the Australian Alps, a much less misty environment than Macquarie Island, 3–7% of precipitation comes from fog drip (Costin & Wimbush 1961).

INTERACTIONS BETWEEN SCIENCE AND MANAGEMENT

Macquarie Island was primarily managed as a scientific station between 1948 and the early 1970s. Scientists employed by the Commonwealth, such as Bill Taylor (Taylor 1955), and those visiting to undertake research, such as Alec Costin (Costin & Moore 1960), raised scientific and bureaucratic awareness of the vegetation deterioration associated with rabbits on Macquarie Island. The Tasmanian Department of Agriculture, in co-operation with the CSIRO and ANARE, investigated and trialled 1080 poisoning and introduction of the *Myxoma* virus as control methods, and found neither to be effective (Sobey *et al.* 1973). Their solution was to introduce the European Rabbit Flea, *Spilopsyllus cuniculi* (Dale), as a vector for the virus (Sobey *et al.* 1973, Skira *et al.* 1983).

Peter Murrell, the first director of the Tasmanian National Parks and Wildlife Service (PWS), which was established in the early 1970s, took the approach that those who undertook research on wildlife species should also be responsible for developing and implementing management regimes for their conservation. From the 1970s onwards, PWS researchers/managers became regular visitors to the islands, setting up monitoring and observation programs, many of which have persisted to the present. Their observations of bird and mammal populations, and their work with permanent plots and exclosures, reinforced the earlier conclusion that rabbits were a major management problem, directly threatening native vegetation and indirectly threatening bird species. The previous establishment of the European Rabbit Flea as a vector for the *Myxoma* virus allowed PWS to introduce the virus to the scattered rabbit populations on the island, and maintain its efficacy in controlling rabbit populations by a program of continuous reintroduction (Brothers & Copson 1988). However, even in 1983, after the myxomatosis-induced crash in rabbit populations, they were in the process of investigating other means of rabbit control, because of the lack of ubiquity of the flea (Skira *et. al.* 1983).

From the 1970s onwards, one of the major responsibilities of the PWS rangers on the island was to control cats, which had been shown by earlier research to be threatening the local extinction of several bird species (Copson & Whinam 2001). PWS produced a cat eradication plan (J.J. Scott 1996), which recognised that the eradication of cats might have consequences for the populations of other pest species, but which anticipated that the current rabbit control program would continue to be effective. The cessation of production of the *Myxoma* virus in 2000 was totally unpredictable at the time. The cat eradication plan, as part of an integrated vertebrate pest management strategy (Copson & Whinam 2001), recognised cat, rabbit and rodent eradication as the desired goal, but only cat eradication as currently feasible, which it was, with all cats being killed between 1998 and 2001. Predictions of the recovery of bird populations after cat extermination were verified (Brothers & Bone 2008).

At the same time as the last *Myxoma* was produced by the Commonwealth Serum Laboratories in 2000, the integration of science and management within PWS was history, the Tasmanian State Government having bureaucratically separated its wildlife scientists from park management personnel, probably because it saw scientific input as an obstacle to tourism development (Kirkpatrick 2001). The scientific program of the part of the Commonwealth bureaucracy responsible for the Antarctic and sub-Antarctic (AAD) was also in a state of rapid transformation, from researcher-led inquiry to inquiry directed by strategic plans and tested by peer review. While the strategic plans developed by the AAD gave priority to understanding the risks presented by climate change to the biota of the sub-Antarctic islands, and consistency with the plans was a major criterion in judgement of competing projects, the other criteria related to the scientific merit of projects and investigators.

Peer review processes favour those scientists who publish prolifically in journals with high citation rates and are capable of convincingly framing their research proposals within the major strategic goals of the granting body. Journals with high citation rates publish work that breaks theoretically new ground, preferably work that uses the very latest, or novel, techniques. Research that can aid management is seldom at this rarefied level, tending more to the idiographic than the nomothetic, and to well-established and reliable techniques rather than innovative techniques. Strategic research plans are very good at addressing the historic concerns of those who control their content, but not as good as independent scientists or scientist/managers in rapidly addressing unanticipated concerns.

In 2000, fissures developed between the State government bureaucracy responsible for the management of the island and its wildlife and the AAD. This fissure was occasioned by the public controversy over the hot-iron branding of Southern Elephant Seals as part of a long-term AAD population research program (Vertigan 2007). The PWS and the permit-granting scientists, now based independently in the Department of Primary Industries, Water and Environment, became more assiduous in controlling the research activities funded by the AAD, to the degree to which some projects had to be abandoned at late notice.

In response to the resurgence of rabbit numbers from 2002 onwards, State scientists, State managers, the AAD scientists and independent scientists funded within AAD programs independently collected data on the consequent massive vegetation changes. The unpublished results of some of the research were critical in the arguments made by independent scientists and non-government organisations for funding of the program (e.g., Scott *et al.* 2007), arguments that had to obtain an extremely high public profile before both governments would accept their responsibilities under the World Heritage Convention.

Two refereed papers on vegetation changes that resulted from the rabbit resurgence (Scott & Kirkpatrick 2008, Bergstrom *et al.* 2009) were published soon after the decision was made to fund the rabbit and rodent eradication program. The former paper resulted from the long-term monitoring work of university and independent scientists. Its publication received little media attention because the results and conclusions of the work had already been well-publicised. The authors concluded that the rabbit and rodent eradication program was well-justified and that it was not possible to ascribe the rabbit resurgence to any specific cause. The second paper reported the work of AAD and associated scientists. It was in a highly prestigious international journal, received special praise from the journal editor (Cadotte 2009) and was the subject of a large number of national and international media reports. The theoretical idea of "ecological cascades", the use of the latest remote sensing and statistical techniques, and a critique of previous management had produced a paper of great academic and popular interest. The paper concluded that State scientists and managers had inadvertently caused substantial ecological damage requiring a greater than $A24 million rabbit and rodent eradication program by their unprescient decision to eliminate cats. The longstanding PWS plans for rabbit and rodent eradication, independent of the fate of cats (Skira *et al.* 1983, Copson 1995, J.J. Scott 1996), and the lack of convincing evidence that cat eradication was largely responsible for the rabbit population increases (as discussed above) were ignored. It was ironic that one of the best examples in the world of the use of scientific research for effective biodiversity management (the integrated pest management process) should have received such a bad international press, a press that could unfortunately make it more politically difficult in future to eradicate damaging vertebrates from other islands.

The above history and previous work (e.g., Copson & Whinam 2001, Frenot *et al.* 2005) have shown that research work has been invaluable in determining appropriate conservation management on the sub-Antarctic islands. It has also been invaluable in determining the vegetation changes that are intractable to management and those that do not require management. Vegetation changes that have resulted from global climatic change are not amenable to local management in themselves, although where climate change interacts with other more controllable factors management action may be possible (Calder & Kirkpatrick 2008). One such interaction on Heard Island and Macquarie Island is with the exotic plant species that might be able to invade as climate changes. They may be prevented from invading, using quarantine procedures developed from research on invasion processes (Whinam *et al.* 2005), or eliminated when their populations are small, as in the cases of *Anthoxanthum odoratum* L. and *Rumex crispus* L. on Macquarie Island (Copson & Whinam 2001). Decades of collection of plot data on Macquarie Island (Scott & Kirkpatrick 2008) and 13 years of observation on Heard Island (Scott & Kirkpatrick 2005) have indicated that *Poa annua* is not a threat to native vascular plant biodiversity, which is fortunate, as its elimination would be close to impossible.

The history of the interaction of science and conservation management on Macquarie and Heard islands suggests that long-term involvement of individual scientists, especially when engaged in management planning as well as research, is one major key to success in management, if not in science, and that science has generally served conservation management well. A greater emphasis on integration of science and management and a greater financial priority for laborious data collection and monitoring activities, which provide the raw material for an understanding of any natural system, may allow the same statement to be made a decade into the future.

ACKNOWLEDGEMENTS

I thank Jenny Scott for her criticisms of drafts of this paper. I also thank the Australian Antarctic Division for making my research on the sub-Antarctic islands possible, and the Tasmanian State bureaucracy, in its various manifestations, for providing permissions for, and help with, research on Macquarie Island.

REFERENCES

Bergstrom, D.M. 1986: Evidence from fossils for uplift during the Holocene in Green Gorge. *Colloque sur les Ecosystemes Terrestres Subantarctiques. Comite National Francais des Recherches Antarctiques* **58**: 73–82.

Bergstrom, D.M., Lucieer, A., Kiefer, K., Wasley, J., Belbin, L., Pederson, T.K. & Chown, S.L. 2009: Indirect effects of invasive species removal devastate world heritage island. *Journal of Applied Ecology* **46**: 73–81.

Bergstrom, D.M. & Selkirk, P.M. 2007: Human impacts on sub-Antarctic terrestrial environments. *Papers and Proceedings of the Royal Society of Tasmania* **141**: 159–168.

Brothers, N. & Bone, C. 2008: The response of burrow-nesting petrels and other vulnerable bird species to vertebrate pest management and climate change on sub-Antarctic Macquarie Island. *Papers and Proceedings of the Royal Society of Tasmania* **142**: 123–148.

Brothers, N.P. & Copson, G. 1988: Macquarie Island flora and fauna management – interpreting progress and predictions for the future. *Papers and Proceedings of the Royal Society of Tasmania* **122**: 129–135.

Brothers, N.P., Eberhard, I.E., Copson, G.R. & Skira, I.J. 1982: Control of rabbits, *Oryctolagus cuniculus*, on Macquarie Island by myxomatosis. *Australian Wildlife Research* **9**: 477–485.

Brothers, N.P., Skira, I.J. & Copson, G. 1985: Biology of the feral cat *Felis catus* (L.) on Macquarie Island. *Australian Wildlife Research* **12**: 425–436.

Cadotte, M.W. 2009: Editor's choice: unintended trophic cascades from feral cat eradication. *Journal of Applied Ecology* **46**: 259.

Calder, J.A. & Kirkpatrick, J.B. 2008: Climate change and other factors influencing the decline of the Tasmanian cider gum (*Eucalyptus gunnii*). *Australian Journal of Botany* **56**: 684–692.

Carmichael, N. 2007: Macquarie Island, its conservation and management. *Papers and Proceedings of the Royal Society of Tasmania* **141**: 11–17.

Chapuis, J.-L., Frenot, Y. & Lebouvier, M. 2004: Recovery of native plant communities after eradication of rabbits from the subantarctic Kerguelen Islands, and influences of climate change. *Biological Conservation* **117**: 167–179.

Copson, G. 1995: An integrated Vertebrate Pest Strategy for subantarctic Macquarie Island. Proceedings of the 10th Vertebrate Pest Control Conference, Hobart, May 1995: 29–33.

Copson, G. 2004: *Draft Plan for the Eradication of Rabbits and Rodents on Subantarctic Macquarie Island.* Report for the Natural Heritage Trust, Department of Primary Industries, Water and Environment, Hobart: 76 pp.

Copson, G., Brothers, N.P. & Skira, I.J. 1981: Distribution and abundance of the rabbit *Oryctolagus cuniculus* (L.) at subantarctic Macquarie Island. *Australian Wildlife Research* **8**: 597–611.

Copson, G. & Whinam, J. 1998: Response of vegetation on subantarctic Macquarie Island to reduced rabbit grazing. *Australian Journal of Botany* **46**: 15–24.

Copson, G. & Whinam, J. 2001: Review of ecological restoration program on subantarctic Macquarie Island: pest management progress and future directions. *Ecological Restoration and Management* **2**: 129–138.

Costin, A.B. & Moore, D.M. 1960: The effects of rabbit grazing on the grasslands of Macquarie Island. *Journal of Ecology* **48**: 729–732.

Costin, A.B. & Wimbush, D.J. 1961: *Studies in Catchment Hydrology in the Australian Alps. IV. Interception by Trees of Rain, Cloud and Fog.* Division of Plant Industry, Commonwealth Scientific and Industrial Research Organisation Technical Paper No. 16.

Cumpston, J.S. 1968: Macquarie Island. *ANARE Scientific Report,* Series A (1). Antarctic Division, Department of External Affairs: 380 pp.

Frenot, Y. 2007: Research activities in the sub-Antarctic. *Papers and Proceedings of the Royal Society of Tasmania* **141**: 111–114.

Frenot, Y., Chown, S.L., Whinam, J., Selkirk, P.M., Convey, P., Skotnicki, M. & Bergstrom, D.M. 2005: Biological invasions in the Antarctic: extent, impacts and implications. *Biological Reviews* **80**: 45–72

Hamilton, A. 1894: Notes on a visit to Macquarie Island. *Transactions of the Royal Society of New Zealand* **27**: 559–579.

Jackson, A. 2007: International instruments and arrangements in the sub-antarctic. *Papers and Proceedings of the Royal Society of Tasmania* **141**: 141–148.

Kirkpatrick, J.B. 2001: Ecotourism, local and indigenous people, and the conservation of the Tasmanian Wilderness World Heritage Area. *Journal of the Royal Society of New Zealand* **31**: 819–829.

Kirkpatrick, J.B. & Kiernan, K. 2006. Natural heritage management. *In* Lockwood, M., Worboys, G.L. & Kothari A. (eds). *Managing Protected Areas: A Global Guide.* Earthscan, London: 421–447.

Kirkpatrick, J.B. & Scott, J.J. 2002: Change in undisturbed vegetation on the coastal slopes of Subantarctic Macquarie Island 1980–1995. *Arctic, Antarctic and Alpine Research* **34**: 300–307.

Landau, D. 2007: Tourism in polar regions and the sub-antarctic islands. *Papers and Proceedings of the Royal Society of Tasmania* **141**: 173–180.

Mawson, D. 1943: Macquarie Island: its geography and geology. AAE Scientific Report, Series A (5).

Pendlebury, S.F. & Barnes-Keoghan, I.P. 2007: Climate and climate change in the sub-Antarctic. *Papers and Proceedings of the Royal Society of Tasmania* **141**: 67–82.

Ruddell, A. 2006: An inventory of present glaciers on Heard Island and their historical variation. *In* Green, K. & Woehler, E.J. (eds): *Heard Island: Southern Ocean Sentinel.* Surrey Beatty & Sons, Chipping Norton: pp. 28–51.

Saunders, K.M. 2008: Palaeolimnology as a management tool for Australian aquatic ecosystems. Unpublished PhD thesis, University of Tasmania.

Scott, J.H. 1882: Macquarie Island. *Transactions of the Royal*

Society of New Zealand **15**: 484–493.
Scott, J.J. 1988: Rabbit distribution history and related land disturbance, Macquarie Island. *Papers and Proceedings of the Royal Society of Tasmania* **122**: 255–266.
Scott, J.J. 1989: New records of vascular plants from Heard Island. *Polar Record* **25** (152): 37–42.
Scott, J.J. 1990: Changes in vegetation on Heard Island 1947–1987. *In* Kerry, K.R. & Hempel, G. (eds): *Antarctic Ecosystems: Ecological Change and Conservation*. Springer-Verlag, Berlin: 61–76.
Scott, J.J. 1996: A feral cat threat abatement plan for Macquarie Island. Tasmanian Parks and Wildlife Service, Department of Environment and Land Management.
Scott, J.J. & Bergstrom, D.M. 2006: Vegetation of Heard and McDonald Islands. *In* Green, K. & Woehler, E.J. (eds): *Heard Island: Southern Ocean Sentinel.* Surrey Beatty & Sons, Chipping Norton: 69–90.
Scott, J.J. & Kirkpatrick, J.B. 1994: Effects of human trampling on the sub-Antarctic vegetation of Macquarie Island. *Polar Record* **30**: 207–220.
Scott, J.J. & Kirkpatrick, J.B. 2005: Changes in subantarctic Heard Island vegetation at sites occupied by *Poa annua,* 1987–2000. *Arctic, Antarctic and Alpine Research* **37**: 366–371.
Scott, J.J. & Kirkpatrick, J.B. 2008: Rabbits, landslips and vegetation change on the coastal slopes of subantarctic Macquarie Island, 1980–2007 – implications for management. *Polar Biology* **31**: 409–419.
Scott, J.J., Kirkpatrick, J.B. & Baxter, T. 2007: Macquarie Island in Danger. Worldwide Fund for Nature, Australia, Sydney: 20 pp.
Selkirk, D.R., Selkirk, P.M., Bergstrom, D.M. & Adamson, D.A. 1988: Ridge top peats and palaeolake deposits on Macquarie Island. *Papers and Proceedings of the Royal Society of Tasmania* **122**: 83–90.
Selkirk, D.R., Selkirk, P.M. & Griffin, K. 1983: Palynological evidence for Holocene environmental change and uplift on Wireless Hill, Macquarie Island. *Proceedings of the Linnaean Society of New South Wales* **107**: 1–17.
Selkirk, J.M. 1996: Peat slides on subantarctic Macquarie Island. *Zeithschrifte fur Geomorphologie N. F.* **105**: 61–72.
Skira, I.J., Brothers, N.P. & Copson, G.R. 1983: Establishment of the European rabbit flea on Macquarie Island. *Australian Wildlife Research* **10**: 121–127.
Sobey, W.R., Adams, K.M., Johnston, G.C., Gould, L.R., Simpson, K.N.G. & Keith, K. 1973: Macquarie Island: the introduction of the European rabbit flea *Spilopsyllus cuniculi* (Dale) as a possible vector for myxomatosis. *Journal of Hygiene* **71**: 299–308.
Taylor, B.W. 1955: The flora, vegetation and soils of Macquarie Island. ANARE Scientific Report, Series B (2). Antarctic Division, Department of External Affairs: 190 pp.
Thost, D. & Allison, I. 2006: The climate of Heard Island. *In* Green, K. & Woehler, E.J. (eds): *Heard Island: Southern Ocean Sentinel.* Surrey Beatty & Sons, Chipping Norton: 52–68.
Turner, P.A.M., Scott, J.J. & Rosefelds, A.C. 2006: Probable long distance dispersal of *Leptinella plumosa* Hook. f. to Heard Island. *Polar Biology* **29**: 160–168. [this is not Andrew Rozefelds from TMAG?]
Vertigan, P. 2007: Ethics and scientific research on wild animals: a case study of the demise of the southern elephant seal research program. Unpublished GradDipEnvSt (Hons) thesis, School of Geography and Environmental Studies, University of Tasmania.
Whinam, J., Chilcott, N. & Bergstrom, D.M. 2005: Subantarctic hitchhikers: expeditioners as vectors for the introduction of alien organisms. *Biological Conservation* **121**: 207–219.
Whinam, J. & Copson, G. 2006: *Sphagnum* moss: an indicator of climate change in the sub-Antarctic. *Polar Record* **42**: 43–49.
Whinam, J., Copson, G. & Chapuis, J.L. 2006: Subantarctic terrestrial ecosystem conservation and management. *In* Bergstrom, D.M., Convey, P. & Huiskes, A.H.L. (eds): *Trends in Antarctic Terrestrial and Limnetic Ecosystems: Antarctica as a Global Indicator.* Springer, Dordrecht: 297–316.
Whinam, J., Selkirk, P.M., Downing, A.J. & Hull, B. 2004: Return of the megaherbs: plant colonisation of derelict ANARE station buildings on sub-Antarctic Heard Island. *Polar Record* **40**: 235–243.

(accepted 6 October 2009)