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RESEARCH

The eradication of Campbell Island sheep and subsequent ecological response

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Abstract: Feral sheep were eradicated from Campbell Island (Motu Ihupuku) – a National Reserve, Nature Reserve and UNESCO World Heritage Site in subantarctic New Zealand – in three distinct stages from 1970 to 1991. The sheep derived from farming attempts on the island, starting in 1895 and abandoned by 1931. The potential genetic and commercial value of the isolated sheep population meant proposed eradication plans were not wholly supported. Compromise solutions were initially implemented that required the construction of two fences, one in 1970 and one in 1984, to separate three geographic portions of the island. This separation was to facilitate staged removal of sheep and vegetation recovery in one portion of the island whilst retaining the sheep in another portion until eradication was fully committed. Sheep were largely removed by small field teams of experienced hunters using standard ground-hunting procedures in three separate operations, with follow-up operations required to remove small numbers of survivors in all three events. Approximately 7000 sheep were shot over the three operations or associated control/eradication efforts. A significant ecological response has been reported, including a recovery in range, abundance, and individual plant size for subantarctic macroforbs (*Anisotome* spp., *Azorella polaris*, and *Pleurophyllum* spp.), but also for grasses (*Chionochloa antarctica* and *Poa* spp.).

Keywords: Campbell Island, eradication, sheep, subantarctic, vegetation

Introduction

Campbell Island (Motu Ihupuku) (52.54°S, 169.15°E) is an 11 268 ha National Nature Reserve, situated 660 km south of the South Island of New Zealand, in New Zealand's subantarctic region. It is a significant breeding site for seabirds, particularly albatrosses, petrels and penguins, containing the majority of the total world breeding population for some species, including the southern royal albatross (*Diomedea epomophora*) and Campbell black-browed albatross (*Thalassarche impavida*). Several bird taxa, including the endangered Campbell Island teal (*Anas nesiotis*) and Campbell Island snipe (*Coenocorypha aucklandica perserverance*), are endemic to the island. Many of its plants are endemic to New Zealand's subantarctic islands, and 40% of the invertebrates are unique to Campbell Island. Vegetation is largely comprised of a zone of shrubland from the coast to 200 m above sea level (predominantly *Dracophyllum* spp., *Coprosma* spp., with *Myrsine divaricata* and *Veronica elliptica*) and extensive grasslands with tussock-forming *Poa litorosa* and *Chionochloa antarctica*, along with macroforb (macrophyllous forbs hence macroforb, also known as megaherbs) species such as *Pleurophyllum* spp., *Anisotome* spp., *Azorella polaris* and *Bulbinella rossii*. Prior to Campbell Island's official designation as a Flora and Fauna Reserve in 1954, it was used as a base for farming, whaling and sealing ventures. The reserve classification was amended to Nature Reserve status in 1977, with an over-arching National Reserve status added in 1986, New Zealand's highest protected land status. The island is also classified as part of a World Heritage Site, a further indication of its global conservation value.

Liberations of sheep and goats from 1865 for potential castaway use did not successfully establish (Cockayne 1909). Farming began on Campbell Island in 1895, when a grazing lease was issued and 300–400 merino or merino crossbreed sheep were introduced (Otago Daily Times 1895), with a further 3000 similar breed sheep added in 1901 (Southland Times 1901). It was estimated that half the island was grazed by 1903 (Cockayne 1903) and two-thirds of the island by 1909 (Laing 1909). Sheep numbers had increased to 8500 by 1909–10, but decreased to about 4000 by 1931 due to overgrazing and exhaustion of the indigenous pastures (Rudge 1986). Farming was abandoned in 1931 as it was no longer economic, and the sheep were left on the island when the human residents departed. The farmed, and later feral, sheep along with associated burning and introduction of various forbs and grasses meant the vegetation of Campbell Island had been severely modified since early naturalists recorded its natural state (Ballance 1985). In addition to the sheep, during the farming era a small number of cattle *Bos taurus* (in 1902; Wilson & Orwin 1964) and cats *Felis catus* (c.1904; Fraser 1986) were introduced as domestic animals, and both species later became feral. Norway rats *Rattus norvegicus*

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had established earlier (by 1867; Dilks 1979), probably from sealing endeavours in preceding decades.

The sheep became feral and the population initially declined, with the overall population estimated to be less than 1000 in 1961 (Wilson & Orwin 1964), probably as a result of matted double fleecing and fleecy tails impeding copulation and thus lowering productivity (Rudge 1986). A period of climatic cooling may also have had an influence on numbers during this period. The sheep naturally developed a fleece-shedding capability and early maturation to cope with this pressure, and consequently the numbers increased again, to 3000 by 1969 (Taylor et al. 1970). Meteorological Service staff based on the island from 1949–1995 periodically shot a few sheep for meat supply, especially prior to the construction of a freezer in 1976 (N. Judd pers. comm.). Some sport shooting (largely of selected rams for their horns) was also known to occur but both activities occurred at levels insufficient for any effective control of numbers.

The sheep of Campbell Island (Fig. 1) were the subject of numerous studies, with those of Ballance (1985) and Rudge (1986) being the most detailed in aspects of morphology, behaviour, population dynamics, age classes and reproductive biology. Ballance found that the animals grazed in small flocks of 3–12, but individuals within these groups continually changed. However, marked individuals tended to occupy specific home ranges averaging 41 ha for males and 45 ha for females. Ewes comprised 53% of the population and rams 47%. Lambing occurred over a wide period from July to December, but lamb survival rates were low (c. 40% or less), with losses attributed to weather or predation by skuas (*Catharacta antarctica*).

Unlike many feral populations, less than 2% of the population had fully- or part-coloured fleeces. Most rams (c. 67%) had large, curling horns typical of the merino breed, and some females (c. 20%) had smaller horns (Rudge 1990), though Ballance (1985) found 81% and c. 10% respectively, with variation according to location on the island. A relatively high proportion of sheep survived beyond 2 years compared to other feral populations, and a very few individuals reached 11 years old but tooth-wear was severe. The sheep ranged widely over all of the accessible parts of the island, but appeared to prefer the mid-slopes of induced sward, above the dense coastal band of Dracophyllum scrub (*Dracophyllum* spp.). Energy demands meant most time was spent grazing, with only c. 16% of time ruminating (Ballance 1985).

As early as 1907 scientists from the Philosophical Institute of Canterbury recorded the effect of sheep grazing on the vegetation. Later, Guthrie-Smith (1936) noted that the stock was defiling the natural landscape. Continued concern was expressed about the overgrazing caused by sheep, leading to deterioration of vegetation (Sorenson 1954), or creation of peat scarps and thus potential reduction of nesting habitat for royal albatross (Westerkov 1963).

Some concern was held over the effect of sheep on albatross numbers and breeding success (Guthrie-Smith 1936; Westerkov 1963); while counter views suggested the opening-up of dense tussock made more nesting sites available (Sorenson 1950). Much later on, the effect on albatrosses was largely dispelled.

Figure 1. Feral sheep at Penguin Bay, Campbell Island, with a fine turf of cropped grass in foreground and unpalatable *Bulbinella rossii* in the background (Photo: PJ Moors, DOC).

Moore and Moffat (1990) examined the issue and found that food supply was likely the main limiting factor for the albatross population and that the increasing sheep population from 1958–1976 did not have a detrimental effect. They concluded that the quantity or quality of nesting habitat was likely only limited during prolonged periods of high sheep density, for example during the farming era.

The traits of the feral sheep and their adaptation to the Campbell Island environment meant there was interest in their physiology and genetics (e.g. Whitaker & Rudge 1976), as they were thought to have been isolated from more recent cross-breeding and might have developed adaptations to cope with their local environment. This scientific interest had to be balanced against the detrimental effects of grazing on the vegetation composition and structure. In order to accommodate the opposing views, and to facilitate the evaluation of the effect of sheep on the flora and fauna, the Ecology Division of the Department of Scientific and Industrial Research (DSIR) proposed that sheep should be removed from half the island. They also proposed that a long-term research and management programme be implemented (Wilson & Orwin 1964). This recommendation was accepted by the Outlying Island Reserve Committee, the advisory board responsible to the Department of Lands and Survey for advice on management of its offshore island nature reserves.

At a meeting of a subcommittee of the National Parks Authority in March 1967, Dr E.J. Godley of the Botany Division DSIR presented a report on the Campbell Island sheep. He considered the effects of the sheep were: (1) replacement of the palatable *Chionochloa antarctica* grassland with unpalatable *Poa litorosa*; (2) clearance of the Dracophyllum scrub around Perseverance Harbour; (3) a considerable increase in unpalatable *Bulbinella rossii*; and (4) a considerable decrease in the number of many striking subantarctic endemic plants. Added to these effects was serious and extensive erosion (Kenworthy 1980).

A chance visit by DSIR scientist Rowley Taylor and Wildlife Service officer Brian Bell in 1969 confirmed a significant increase in sheep numbers from counts in previous years. At a meeting called later that year to discuss the situation, the decision was made to begin the sheep control programme, with a view to eventual eradication. To achieve a suitable balance between the views, it was proposed that a fence be constructed to effectively cut the island and its sheep population in half. All sheep on the northern side of the fence would be removed by shooting.

Methods

The only method employed for sheep control (and their eventual eradication) was shooting. The use of fences to split the island into sections allowed staged shooting of sheep within a designated control section. The fences were not established to facilitate island-wide eradication delivery but to allow different management options in the different sections of the island, as island-wide eradication was at the time not wholly supported. Shooting was conducted entirely by ground hunters. Sheep were either driven or mobbed for culling by groups of shooters (generally when sheep numbers were high) or were stalked by single or paired hunters when numbers had dropped.

Stage 1: 1970

In January/February 1970, a post and wire-netting sheep fence was built by a Wildlife Service-led field party, that also contained a number of scientists involved in the sheep research. The fence materials had previously been air-dropped in by the Royal New Zealand Air Force. The dropped loads were widely spread over the area, and some had to be retrieved from kilometres away (N. Judd pers. comm.).

The constructed fence ran across a relatively narrow waist of the island, from the head of Tucker Cove (grid ref NZMS272/3 374080 176400) in the east, to the western edge of Col ridge (372900 177500), a distance of approximately 1.75 km (see Fig. 2). This fence effectively divided the island into two similar-sized blocks, with sheep to be removed from the northern half. This northern area was estimated to be 5700 ha. The fence generally fulfilled its purpose of restricting sheep movement between the two areas, although minor problems occurred. Initial faulty construction at the extreme western end (which bounded on tall cliffs) was quickly repaired, and some damage occurred through elephant seal (*Mirounga leonina*) and New Zealand sealion (*Phocarctos hookeri*) activity at the eastern (Tucker Cove) end, though this was also quickly repaired. The damage caused by the sea mammals was a continuing problem over the next few years.

Sheep north of the dividing fence were shot using .22 and .222 rifles, concentrating on a single defined sub-block at a time, with up to 12 personnel involved in driving and shooting the sheep. The 1970 field team was Brian Bell, Dick Veitch, Chris Robertson, Kerry Horgan, Bob Simpson and Chris Smuts-Kennedy (all Wildlife Service); Mike Rudge, Rowley Taylor and P. Ross (all DSIR); Colin Meurk (University of Canterbury); A. Thorpe (Department of Lands and Survey); and M. Soper (medical officer). The 1971 team included Don Merton, Roger Gould and Kerry Horgan (all Wildlife Service); Peter Dilks and Peter Wilson (DSIR); and Colin Meurk.

Stage 2: 1984

The sheep population south of the fence continued to rise, from 2500 in 1971 to 3500 in 1983 (Dilks & Grindell 1983). Concerns were again expressed about the relative conservation priorities, especially in view of the reports of obvious and dramatic recovery of vegetation following removal of sheep from the northern half of the island in 1970. Within the area continuing to be grazed by sheep, the long-term effects of such modifying influences were still very much in evidence. Rudge (1990) noted that large endemic herbs and palatable tussock grasses had almost been eliminated by sheep and fire, and that the sheep now fed on induced swards.

As part of the development of the management plan for the island, the Department of Lands and Survey canvassed expert opinion on the value and the fate of the sheep. It concluded that the highest conservation priority was to protect the survival of any plant species or community by removing the threat of sheep (Department of Lands and Survey 1982). The department also summarised that in submissions to the review of the management plan there was support that the decision on the sheep's future should not be postponed.

Foggo (1981) provides an example of the views of the pro-eradication lobby, while suggesting a concession that was to be accepted as the approved policy. "The experiment of the exclusion of the sheep has gone on long enough for the results to be clear. I do not see the need that the exceptional vegetation of the subantarctic reserve needs to be further subjected to modification by introduced grazing mammals. I would therefore like to see sheep removed from the island and would only consider their continuing presence in the event

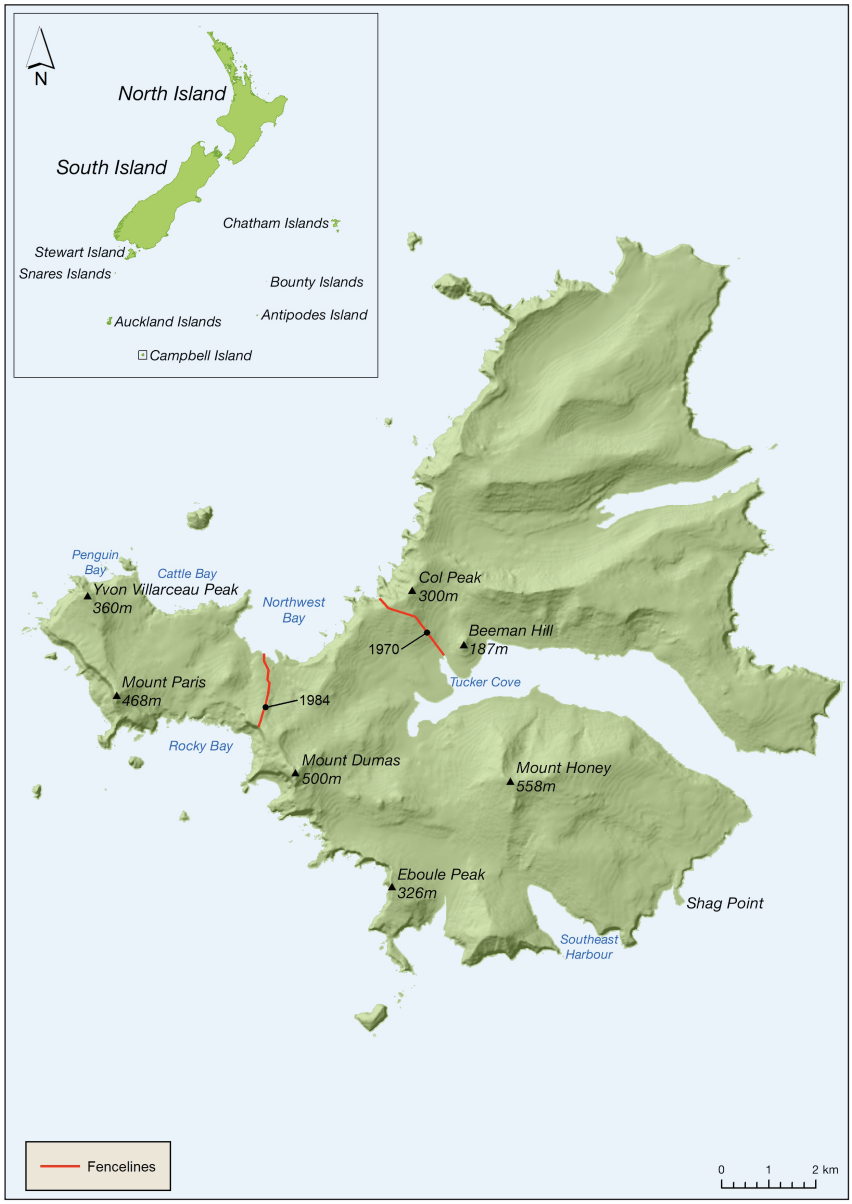

Figure 2. Campbell Island, showing the 1970 and 1984 sheep fences and the three sheep control sectors.

of some proposals for significant research on them. If such proposals were forthcoming then the sheep should be restricted to a much smaller part of the island. In particular, Mt Honey, which as the highest part would be expected to show the most spectacular altitudinal sequences, should be free of sheep".

Some counter arguments were produced, with Wilson and Taylor (1983) arguing that the scientific value of the sheep was not just for agricultural reasons but also for study of the evolutionary aspects of an unmanaged population. The retention of sheep on the island for further study was supported in other quarters due to the proven scientific interest and possible agricultural value of the sheep and their wool (W.S. Simpson, Director of WRONZ, 1982 letter to Lands & Survey).

As a compromise between the views, the option adopted for the management plan was to reduce the area occupied by sheep by construction of a second fence, to isolate the sheep to an 800 ha area on the southwestern corner of the island (see Fig. 2, 1984 fence line). All sheep east of that fence line (in the c.4800 ha 'Honey' block) would be culled.

Consequently, the policy for the approved management plan of 1983 read: "to preserve for at least 5 years a minimum population including about 400 ewes, confined in their range in such a way that they: (a) do not threaten the survival of any indigenous taxa of flora and fauna, or (b) do not diminish other scientific features of the reserve, and (c) are maintained in a wild state" (Department of Lands and Survey 1983, p 53). A further policy was to foster ongoing research into the significance of the sheep population for maintaining and developing the genetic diversity of domestic sheep.

The proposed fence line would remove sheep grazing from areas occupied by at least five species of plant not found in the previously fenced off northern section. These species (*Leptinella dispersa* subsp. *dispersa*, *Leptinella lanata*, *Lobelia arenaria*, *Carex edura*, and *Brachyscome radicata*) appeared associated with soils overlying schist, limestone and mudstone on and west of the St Col-Dumas ridge (Given 1982). Mt Honey was considered as an important habitat from which to remove all sheep due to its broader altitudinal zonation (Department of Lands and Survey 1982).

The fenced off western section of the island was intended to hold a sheep population of at least 500 animals for maintenance of genetic diversity. This option was chosen as

the most appropriate avenue for progress, but necessitated the eradication of a small number of feral cattle in the area (see Brown & Cox 2022), the home range for which straddled the proposed fence line and their continued presence could have threatened the fence security.

The second fence was constructed in 1984, and ran from Capstan Cove in Northwest Bay (grid ref NZMS 272/3 370500 176000) to the southern cliff edge west of Mt Dumas and overlooking Rocky Bay (370300 174680), a total length of approximately 1.4 km. Although sheep could graze the slopes beneath the southern cliff at the south end, they could not travel further east due to further cliff barriers, and this section did not need to be fenced. The fence also did not reach the coast on the Northwest Bay side, stopping short of a dense Dracophyllum scrub area thought to be both unsuitable for fencing and impenetrable to sheep. However, it later became apparent that sheep were using trails through this scrub, and the 1983/84 Meteorological Service team erected a temporary netting fence to the coast as a 'stop-gap' measure. In 1985/86 Lands and Survey staff put in a new end section of the fence on a new line at Northwest Bay to complete the fencing operation.

The original 1970 fence was still present and in 1986 it was recommended it be maintained as a temporary backstop; however, the wire was removed in 1990 and the posts removed in 1992. The 1984 Northwest Bay fence (wire and posts) was also removed in 1992 (G. MacAlister pers. comm.), though some posts remain along both fence lines as vegetation quadrat and transect markers. The fences were necessary to restrict sheep movement between blocks but also caused restriction of movement for wildlife such as sealions and possibly also penguins and albatrosses. One albatross was recorded as being caught on the wire of the Northwest Bay (1984) fence (J. Amey pers. comm.), and at least one in the Tucker Cove (1970) fence (P. McClelland pers. comm.).

The 1984 culling operation (Stage 2, involving an area of c. 4780 ha) was carried out between 18 June and 8 August 1984. It involved four Wildlife Service shooters initially working as a team, sweeping through areas, and occasionally driving flocks of sheep to areas where they could be 'cornered' and shot. As sheep numbers reduced, the team split into pairs or hunted as individuals, enabling a much larger area to be covered. An inflatable dinghy was used to access start points for many days hunting, reducing the extensive travelling time. Rifles used were .243 and .303 calibre, both of which proved effective (Torr 1984). The 1984 field team comprised Nick Torr, Geordie Murman, Rick Thorpe, Leon Cooke (all Wildlife Service), and Alison Ballance (Massey University).

Stage 3: 1990

At the conclusion of Stage 2 in 1984, the sheep population contained to the west of the second fence was estimated to be 900 (Orwin 1984), in an area of c. 800 ha. Despite the culling of over 100 sheep by Meteorological Service staff in 1986 to protect penguin colonies inside the fenced area, Moore and Moffat (1990) found a population of 1105 sheep remained in 1988. This was an obvious increase upon previous numbers, based upon information dating back to 1961. Given their numbers, the sheep were threatening the natural vegetation and landforms of the area where they remained.

Moore (1990) commented on the effects noting that overgrazing had eliminated palatable species (e.g. *Chionochloa antarctica* and *Pleurophyllum* spp.) and had increased induced short sward vegetation and *Bulbinella rossii* meadow. Despite being relatively tolerant to browsing, *Poa litorosa* tussocks were decreasing in stature and some shrubs (*Dracophyllum* spp., *Myrsine divaricata*, *Coprosma* spp.) had died out. In comparison, in the areas cleared of sheep north of the 1970 fenceline, there had been dramatic recoveries with the return of *Chionochloa antarctica* grassland and macroforbs (e.g. *Pleurophyllum speciosum*, *Anisotome latifolia*). Moore and Moffat (1990) also suggested sheep were causing physical disturbance of rockhopper penguin (*Eudyptes filholi*) colonies, damage to burrows of sooty shearwater (*Puffinus griseus*), and reduction of nesting habitat for yellow-eyed penguin (*Megadyptes antipodes*), and that the continued presence of sheep fences restricted inland movement of New Zealand sealion and possibly penguins.

Attention was drawn to the primary objective of the management plan for the island, which was to preserve and maintain the indigenous flora and fauna, ecological associations, and natural environment of the Campbell Islands as far as possible in a natural state and to recognise natural influences and accept the effect of natural processes (Department of Lands and Survey 1983).With a number of Campbell Island sheep in captivity since 1976, and having been the focus of considerable research, the general consensus was that the feral sheep population on Campbell Island had outlived its relative value, while considerable gains in ecological values could be achieved by their complete removal.

The 1990 eradication operation occurred in October/ November 1990, using similar methods to those employed previously. The 1990 field team was Andy Cox, Peter McClelland, Murray Willans, and Shane Hancox (all Department of Conservation), Ron Goudswaard (Wellington Zoo), and Geoff Copson (Tasmanian Parks and Wildlife Service). Rifles used in the 1990 operation were .243 and .303 calibre.

Ecological response

Our ability to understand the drivers of vegetation change on Campbell Island is enriched by the availability of pollen-based histories from across the island, dendrochronological data, historical photo sequences and recent quantitative vegetation monitoring (Meurk 1982; Wilmshurst et al. 2004; McGlone et al. 2007, 2019). Significant changes to the vegetation of Campbell Island pre-date the removal of sheep, with Zotov (1965) making the first account of shrub expansion on the island, something not noted by the earlier 'coastwatcher' naturalists in their detailed accounts of the island's vegetation (1941–45) (McGlone et al. 2007).

Vegetation monitoring has comprised the use of belt transects (pairs run as either continuous, 1970, or discontinuous sections, 1984, on either side of each fence line), 27 quadrats and numerous photo-points (Meurk 1982; Walls 1996). These permanent vegetation plots were established in 1970, 1981 and 1985/86 with the monitoring initially intended to repeat at approximately 5-year intervals (Meurk 1991), and although this regularity has not been achieved the quadrats and transects were remeasured in 2010/11 and are permanently marked, with accurate georeferences, with future monitoring planned.

Results

Stage 1: 1970–1971

Approximately 1281 sheep were shot during the 1970 expedition, but when the main party had to leave an estimated 30 sheep remained (Bell & Taylor 1970). A field team led

by Don Merton returned the following year to mop up the remaining few animals (B. Bell pers. comm.). Elephant seals and/or sealions continued to cause damage to the fence line, permitting some sheep from the southern sector to move into the sheep-free northern zone. In 1975, 12 sheep were shot around Beeman Hill after getting across the damaged Tucker Cove (1970) fence (N. Judd pers. comm.). Prior to this event, other sheep had been shot on the northern side of the fence by Meteorological Service staff.

Stage 2: 1984

The Wildlife Service field party accounted for 3830 sheep over the 7-week field trip. Overall, approximately 200 person-days of effort were put into the hunting operation, but hunting did not occur on some of these days due to unfavourable weather. Locating sheep proved relatively difficult in dense or extensive areas of Dracophyllum scrub, such as on the east flanks of Mt Honey, where sheep could remain out of sight of hunters for days. A small number of sheep were known to remain in the block at the cessation of the trip, but delays in reaching the island and periods of bad weather prevented the completion of the operation, and the team basically ran out of time (N. Torr pers. comm.). Meteorological Service staff continued the culling of the few remaining animals as and when possible. In 1987, sheep were seen and/or shot on the north face of Mt Honey, at Shag Point, and in the Dracophyllum scrub area between Shag Point and South East Harbour, while a solitary animal was shot between Eboule Peak and Mt Dumas about the same time (G. Taylor pers. comm.). Nevertheless, a handful of sheep remained in the 'Honey' block until at least 1991. Some sheep were also able to escape from the remaining (Northwest and Penguin Bays) sheep block but tended to stay close to that area, as distinct from the 'original' survivors of the 1984 campaign, which were mainly in remote areas around Mt Honey.

Stage 3: 1990–1991

The four shooters accounted for approximately 1400 sheep over 6 weeks (A. Cox pers. comm.). Some prior shooting of sheep occurred in localised areas around known rockhopper penguin colonies, most in a coastal area isolated below cliffs running between Mt Paris and Yvon Villarceau Peak, and a further few at Penguin Bay and Cattle Bay (Morrow 1986). This control was largely in an attempt to limit disturbance to penguin breeding colonies, as sheep moving through the colonies had been observed to trample eggs and disturb nesting penguins, causing further losses of eggs and chicks through skua predation (G. Taylor pers. comm.).

It is known that, contrary to express requests from the Department of Conservation (DOC), the Meteorological Service 1988/89 staff team undertook the shooting of sheep in the Northwest Bay block. DOC had encouraged Meteorological Service staff searches and shooting in the previously hunted areas, but had expressed the wish that no prior control occurred in this block before the 1990 operation so that the sheep were not 'educated' or wary towards hunters. The hunting was done in a degree of secrecy, and not officially recorded, therefore only limited anecdotal information is available. The numbers actually controlled by the Meteorological Service staff are not available, but were estimated at greater than 200 and potentially considerably more (P. McClelland pers. comm.).

Some of the last few sheep were wary of humans, but could not continually elude experienced personnel using perseverance and suitable stalking strategies. Meteorological Service staff shot the last few sheep in 1991. Rob Humphries shot two in September of that year, near the top of Mt Honey, and Mike Fraser shot the very last sheep in November 1991 (N. Judd pers. comm.). It was a solitary middle-aged ewe, on the southern slopes below Mt Paris.

In total, c. 6500 sheep were shot over the three separate official operations, with at least 600 more killed by Meteorological Service personnel in supporting efforts (Table 1). Sheep density appeared low in the northern half of the island, with only c. 0.24 sheep per ha shot in Stage 1, compared to >0.8 per ha in the Mt Honey block (Stage 2) and c. 1.75 sheep per ha in the Stage 3 Northwest Bay/Rocky Bay sector. The reasons for the differences in density have not been examined, though studies of sheep numbers (e.g. Rudge 1986) suggested sheep density over the southern half of the island increased appreciably over the latter part of the 20th century, up until their eradication. Information was collected from 1066 animals shot in 1970 (Rudge 1986), and from 2529 animals shot during the 1984 operation (Ballance 1985). Data collected included sex ratios, age classes, occurrence of horns or skurs (shorter horny growths), fleece colour, body size, and timing of reproduction.

Ecological response

A significant increase in the shrub/small tree cover of *Dracophyllum cockayneanum*, *D. longifolium* and *D. scoparium* (and their hybrids) has been occurring on the island since the early-mid 20th century. Analysis of charcoal and pollen from peat profiles, historical photographic sequences, and measurement of the age of Dracophyllum scrub across the island permits insight into the processes leading to the expansion (Wilmshurst et al. 2004; Bestic et al. 2005; McGlone et al. 2007). The scrub cover on Campbell Island was drastically reduced with the onset of a burning regime initiated by farming efforts to clear scrub and improve grass condition between 1895 and 1931 (Meurk 1977). This farming era is apparent in the palynological record; a burning and grazing regime is demonstrated by charcoal followed by an immediate change in vegetation. Scrub abundance, palatable macroforb (*Pleurophyllum* spp. and *Anisotome* spp.) abundance and palatable tussock abundance (*Chionochloa antarctica*) all decline, while the unpalatable macroforb *Bulbinella rossii* and the less palatable tussock *Poa litorosa* both increase (McGlone et al. 2007). The demographic structure of the Dracophyllum scrub sampled by Bestic et al. (2005) indicates the expansion began shortly after farming ended in 1931, accompanied by an abrupt change in the fire regime. Neither the ongoing impact of feral grazing nor warming temperatures from the mid-20th century explain as much of the expansion. One important aspect of this expansion that should be noted is that it does not appear to be coupled with an increase in the altitudinal limit of Dracophyllum scrub on the island; low growing scrub may be continuous in sheltered sites to 250 m, and stunted individuals of *D. scoparium* have been found as high as 396 m (McGlone et al. 2007).

Meurk (1982) has provided a quantitative monitoring record documenting ecological changes that have occurred as a result of sheep removal. The first decade of vegetation monitoring (observations made in 1975/76 and again in 1980/81) quadrats and transects along both sides of the 1970 dividing fence revealed dramatic changes and vigorous regeneration of certain plant communities in the sheep-free northern area. Large endemic macroforbs such as *Anisotome* spp., *Azorella polaris*, and *Pleurophyllum* spp., and the palatable tussocks *Chionochloa antarctica* and *Poa foliosa* (less so and in coastal

Table 1. Summary of sheep eradication operations, Campbell Island 1970–1991.

Control area	Date	Size (ha)	No. of sheep destroyed
Northern section	1970	5700	1281 + c.30–105 shot in 1971 (differing accounts) + 12 shot in 1975 (broke through fence)
Mt Honey block	1984	4800	3830 (WLS, 1984) + c.170 prior to this (Meteorological Service staff) + 12 around Northwest fence by Meteorological Service staff (1984) + 5 on the 1984/85 expedition, one known to remain, plus a small no. at South Pt. (M. Wilson, pers. comm.) + 41 shot east of fence 3/12/85–5/2/86 (31 near fence, 9 on SE flank of Mt Honey and 1 at head of Perseverance Harbour) (Willis 1986) – unconfirmed report of six more on N flank Mt Honey after this trip + 19 (1987) including Mt Honey, Dracophyllum scrub areas east of Mt Honey, Shag Point, near Southeast Harbour, and on the Eboule Peak–Mt Dumas coastline. + 2 by Meteorological Service staff, top of Mt Honey, Sept 1991
Western section	1990	800	130 around penguin colonies (1987) Est. 200+ by Meteorological Service staff, 1988–89 c. 1400, main operation 1990 + at least 6 shot by Meteorological Service staff in 1991

sites) began a spectacular recovery both in terms of size and abundance, replacing the short-grazed sward. *Chionochloa antarctica* tussock numbers increased by over 4000% across the induced *Poa litorosa* meadows within 5 years. Meurk (1982) noted that in the north regeneration was rampant, but in the south where there was ongoing grazing the condition of the vegetation continued to decline, and therefore concluded that north of the fence the subantarctic flora could regain its natural status in the near future. Similarly, Ballance (1985) reported spectacular recovery of macroforbs in the sheep-free northern sector after c. 14 years. It is worth noting that some of the resurgence of the Campbell Island weevil *Oclandius cinereus* (post rat eradication in 2001) should be attributed to the recovery of the *Chionochloa antarctica* tussock, where it is now regularly found around the decaying bases of old blades and tillers.

By 1991, 7 years after removal of the bulk of the sheep, *Pleurophyllum* spp. and *Anisotome* spp. were scattered throughout the Stage 2 Mt Honey section of the island and a few small *Chionochloa antarctica* were starting to grow. By 2001, there was a magnificent display of flowering *Pleurophyllum* spp. through this area (J Amey pers. comm.). In 1991 the southwestern section was dominated by thick *Bulbinella rossii* fields and *Poa litorosa* tussock and the sheep appeared to limit the regrowth and range of the Dracophyllum scrub as well. Photopoints along the 1984 fence line show a dramatic difference not only in the height of the Dracophyllum scrub, but also how far up the hill it extends. The differences in the tussock and macroforb vegetation in the 1984 and 1990 areas remain apparent, although there were *Pleurophyllum* spp. and *Anisotome* spp. plants emerging in the southern section by 2002 (J. Amey pers. comm.).

As of January 2011, the legacy of an extended 14 years of feral grazing south of the 1970 fence line remained obvious with significantly larger *Chionochloa antarctica* tussocks being abundant in the northern half (Figs. 3 & 4). The boundary of the 1984 fence line is much more diffuse, with exotic sward grasses, another legacy of farming effort (especially *Agrostis capillaris*, *Arrhenatherum elatius*, *Holcus lanatus* and *Poa pratensis*), remaining abundant at mid-slope here with similar mixes of sward grasses to be found in other areas around the island.

In some parts of the island the recovery has been slow; on Homestead Ridge for example, *Chionochloa antarctica* tussocks remain stunted. As McGlone et al. (2007) noted, this is likely because the removal of scrub-tussock cover on peat bogs led to a feedback loop of reduced evapotranspiration and increased surface wetness, facilitating wetland species as opposed to tussock or scrub cover. Likewise, in the southern half of the island the abundance of *Azorella polaris* remains low. McGlone et al. (2007) also found that based on pollen abundance *Anisotome* spp. had failed to recover as well as *Pleurophyllum* spp.. For both *Anisotome* spp. and *Azorella polaris* the larger and heavier seeds are slower to disperse, reducing the recovery rate. It is also possible that preferential selection of large seeds by rats up until 2001 also retarded recovery rates (McGlone et al. 2007). Likewise, the intensity of feral sheep grazing up until 1984 in the southern half of the island, and in the southwestern portion until 1990, may have caused excess damage to suppressed seedlings and heavily grazed plants that appear to have survived and recovered in the northern half of the island.

After the last full measure of vegetation quadrat and transects in 2010–11, annual visits from 2012 until 2020 made with tourist groups allowed some ongoing observation of vegetation change in some areas. As noted above, Dracophyllum scrub continues to infill north, east and south-facing parts of the island up to the pre-existing scrub line/tree line. This ongoing expansion is currently most obvious above Capstan Cove in Northwest Bay, where the track that once followed the 1984 fence line (on the immediate west of Whalers Stream) is quickly becoming lost to dense scrubland. Even with ongoing expansion of Dracophyllum scrub the altitude of the tree line on Campbell Island may not increase.

Figure 3. Colin Meurk in 2010 (facing south) indicating the position of the 1970 fence line that bisected the island and removed feral grazing pressure from the northern half of the island (in the background) 14 years before the vegetation in the foreground, which had been ungrazed since 1984 (Photo: AJF; 17 Dec 2010).

Figure 4. Posts indicating the position of the 1970 fence line in 1996. Sheep had not been present in the southern section (to the left of posts) for 12 years, compared to 26 years on the right. *Chionochloa antarctica* tussock has not yet strongly re-established in the southern sector, compared to the strong recovery in evidence to the right (Photo: GH Sherley, DOC).

Recent palynological research spanning the post-glacial tree line ecotone suggests that New Zealand's southern-most and lowest tree line has historically decoupled from adjacent ocean temperature trends, with westerly wind intensities and associated changes in cloud conditions driving solar radiation and evapotranspiration and thus woody vegetation growth (McGlone et al. 2019).

The current vegetation and vegetation-change processes on Campbell Island can be seen to have three distinct sheep farming legacies: (1) the expansion of scrub – predominantly *Dracophyllum* spp. following the cessation of the burning regime; (2) the recovery of endemic palatable macroforbs and grasses following significant reduction in their cover by farmed and feral sheep grazing; and (3) the ongoing localized presence of exotic sward grasses introduced to enrich pasture.

Mainland export

In 1975, a number of Campbell Island sheep were herded in a drive to collect live animals for research purposes. Traits of particular interest for the isolated breed were possible foot-rot and facial eczema resistance, aspects related to wool-shedding, early reproductive maturity, and the high vigour of newborn Campbell lambs compared to standard breeds. Good mothering traits also appear to have been evident amongst the captive flock (N. Judd pers. comm.). The drive from near Mt Dumas to a temporary corral along the central (1970) fence yielded 55 animals from which ten (seven ewes, three rams) were selected for captivity (N. Judd pers. comm.). They were taken from Campbell Island in February 1976 to be held and managed by agricultural scientists from Ruakura. By 1981 the flock was breeding satisfactorily and numbered 30 individuals (F.R. Cockrem, unpubl. data, 1981 letter to Lands and Survey).

Belated interest in the possibility of obtaining further live sheep from Campbell Island was expressed in 1990, after prior enquiries for expressions of interest by DOC had elicited no response. By this stage the final eradication operation was well underway, and only two live lambs could be obtained. These were not considered enough for the intended purposes by the requesting agency and were consequently destroyed (A. Cox pers. comm.). Prior to 2005, very few sheep (rams only) were distributed to members of rare breed societies such as the Southland Heirloom Breeds Charitable Trust and the Rare Breeds Conservation Society, but no female sheep were made available. Subsequently, commercial interest in the breed has been discontinued, and a small flock has been transferred to private ownership. Furthermore, it appears the sheep may not have been entirely genetically isolated since their introduction. A few stud rams (probably Cheviot) were reportedly introduced in the 1950s, in order to improve the meat production of the feral animals (N. Judd pers. comm.), though it is unclear if they survived and/or bred successfully.

Discussion

The sheep eradication operations were relatively straightforward, compounded largely by logistical requirements, weather conditions and the size and nature of the island, rather than any particular difficulty posed by the quarry itself. Nevertheless, the combined operations were an outstanding effort in an inhospitable environment. They have resulted in a major conservation benefit to the ecosystems of Campbell Island, especially with respect to vegetation communities. Had island-wide eradication been the objective from the outset, the construction of the two sub-dividing fences would probably not have been required or justified. They created relatively minor but anecdotally documented wildlife issues.

The fences were effective in providing temporary boundaries for each control operation, but were not effective as long-term barriers, due to damage by sealions and elephant seals, and the inability for regular maintenance to occur. Consequently, a number of sheep found their way through or around the fences. However, the behaviour of the feral sheep, in occupying relatively small home ranges, meant they did not stray too far from the fence line and were easily able to be located and shot.

Due to repeated damage to the rigid post-and-wire fence by sealions and elephant seals at Tucker Cove, a flexible fence was designed to allow seal movement across it. Posts were inserted into old car tyres that were cemented or part buried. The posts were fastened to the tyres but not dug into the ground themselves. The heavy seals would flatten the fence while moving across it, but it would spring back into place once they had passed the fence. The fence was maintained by Meteorological Service staff, and it remained effective until the 1984 cull effectively eliminated the need for the fence (N. Judd pers. comm.).

The removal of sheep and the associated recovery of vegetation have been suggested (Brown & Theobald 1999) as a possible cause of the subsequent natural extinction of the feral cat population on Campbell Island. Cats were seemingly always very scarce on the island (Dilks 1979) and therefore the population may have been susceptible to any changes in their environment. Taylor (1986) suggested lack of sheltered dry den sites as a possible reason for their scarcity, and estimated the population as <50 cats, and later revised this down to 15–30 cats (G. Taylor pers comm). The last reported cat sign was in 1987 (P. Moore pers. comm.), in the southern sector of the island, 3 years after sheep had been removed from that area. No cats were found in 1999 despite extensive searches with a well-proven cat detection dog (Brown & Theobald 1999). The recovery of taller herbaceous vegetation and more specifically loss of sheep trails may have inhibited cat movement, especially hindering the critical need to remain dry in such a damp and cold environment. The terrier dog used in 1999 was a similar size to a large cat and was regularly wet and chilled after walking through the often-damp recovering herbaceous vegetation (DAB pers. obs.). Norway rats formed the bulk of cat prey – at least in summer months (Dilks 1979) – and taller or denser vegetation may also have reduced hunting efficacy. Feral cats occasionally feed on carrion (Fitzgerald 1990), even on carcasses of species as large as elephant seals (Jones 1977) so another possibility, though without direct evidence, is that sheep or lamb carcasses could have provided a seasonally important food source for scavenging cats, especially in winter when other food sources (rats, birds, insects) are typically at their lowest ebb on subantarctic islands.

Most elements of the Campbell Island biota have exhibited obvious and positive responses to the removal of all exotic mammals from the island. The bird species, especially the Auckland Island pipit (*Anthus novaeseelandiae aucklandicus*), and the endemic teal and snipe have primarily responded to the removal of rats (Miskelly & Fraser 2006; Armitage 2007; McClelland 2011). Likewise, the invertebrate response, particularly that of large-bodied endemic species such as the Campbell Island weta (*Notoplectron campbellense*) and the

Campbell Island weevil, is primarily attributable to rat removal (McClelland 2011). However, the island's vegetation is primarily responding to the removal of sheep and the cessation of sheep farming practices.

In some respects, the ecological response to sheep eradication could be confounded by the eradication of cattle in 1984 and the 2001 eradication of Norway rats. However, cattle numbers were low, and they were limited to a small geographic area, and vegetation monitoring (Meurk 1982, 1991) in sheep-cleared zones prior to rat eradication showed dramatic changes that could only be attributable to sheep removal. With the successful removal of sheep and cattle (Brown & Cox 2022), the subsequent disappearance of feral cats, and the eradication of Norway rats in 2001, Campbell Island is now entirely free of introduced mammals. In such a pest-free, albeit not weed-free, environment Campbell Island's already outstanding ecological values have the opportunity to recover to near natural conditions.

Author contributions

DAB compiled historical records; AJF assisted in collection of botanical data; and DAB and AJF wrote the manuscript with input from FSC.

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