The common brushtail possum in New Zealand—an unfinished battle with an alien invasive marsupial

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Abstract : Brushtail possums (*Trichosurus vulpecula*) were introduced into New Zealand from Australia in the mid 1800's to establish a fur industry. They became a major invasive pest damaging native biodiversity by browsing and predation, and harming the farm industry by acting as reservoir of bovine tuberculosis. Management of possums includes eradication from some offshore islands and control by trapping, shooting and poisoning on the mainland. Although successfully eradicated from some islands and greatly reduced in abundance in some areas with high conservation value, possum distribution on the mainland has continued to expand. They are still at very high density in some areas and continue to cause biodiversity loss in this country. The efficiency of conventional control methods is affected by limited funding and rapid population recovery caused by re-colonisation, higher reproduction rate and survival rate of possums in response to reduced density. Biological control, especially immunocontraception, is now being investigated as a cheaper and more effective option. Recent studies indicate that the polygynous mating system and some responses of male possums to female sterilisation would help the success of a potential virus-vectored immunocontraception method.

Key words : brushtail possum, *Trichosurus vulpecula*, invasive marsupial, control, biocontrol, New Zealand

Mammal pests in New Zealand

Except two native bat species, *Chalinolobus tuberculatus* and *Mystacina tuberculata*, all land mammals in New Zealand were introduced. A total of 54 mammal species were introduced to New Zealand from Europe, Australia and other regions. Among them 34 species have established (King, 1990). These introduced mammals have caused some severe environmental problems in New Zealand. Rabbits (*Oryctolagus cuniculus*) caused damage to pastoral industry. The native vegetation has been profoundly modified by introduced browsers such as possums (*Trichosurus vulpecula*), goats (*Capra hircus*) and deers (*Cervus elaphus*). Introduced carnivores such as cats and mustelids has caused many extinctions of native birds, lizards and insects (King, 1990). Among mammal pests, the common brushtail possums were regarded as the most serious, not only because it damages the native vegetation and prey on birds and insects, but also it is a natural reser-

voir of bovine tuberculosis.

Brushtail possum biology

The common brushtail possum (*Trichosurus vulpecula*) (Kerr *et al.*, 1992) is endemic to Australia. It is a nocturnal arboreal marsupial weighing about 2 ~ 4 kg. Possums are seasonal breeders, most births occur during autumn but births have also been recorded in all months of the year (Kerle, 1984). Female possums give birth to a single young and twins are rare (Tynedale-Biscoe & Renfree, 1987). The young is born after a gestation period of about 17.5 days (Pilton & Sharman, 1962) and permanently leaves the female's pouch at around 240 days after birth (Fletcher & Selwood, 2000). There is some evidence that young of both sexes disperse when 11 ~ 12 months old (Jolly, 1981), but most studies suggest dispersal in possums is male-biased (Dunnet, 1964 ; Crawley, 1973 ; Clout & Efford, 1984 ; Efford, 1991). Female possums mature at 1 ~ 2 years of age depending on locality and

population demographics , while most males do not start to breed until two years old (Tyndale-Biscoe & Ren-free ,1987).

The common brushtail possum is a very adaptable species (Green , 1984). Its natural distribution in Australia extends from open forests of the tropics , to the cold , temperate forest of Tasmania as well as the arid centre and southwest (Kerle ,1984). It is not restricted to its natural habitat , but also occur in agricultural and urban areas (Satham & Satham , 1997). Although it occurs at high densities in some areas (Satham , 1995) , However , the species has declined greatly throughout most of its natural distribution in Australia (Kerle *et al.* , 1992).

Introduction of possums to New Zealand

Possums were introduced to New Zealand from Australia and Tasmania to establish a fur industry (Pracy , 1974). The first successful introduction was made in 1858 and since then hundreds of liberations of animals from Australia as well as native bred , were made both by Acclimatisation Societies and government agencies (Pracy , 1974 ; McDowall , 1994 ; Clout & Ericksen , 2000). Possums spread rapidly and occupied 92% of New Zealand by 1984 (Cowan , 1990a).

Clout & Eriksen (2000) considered that the possum has become a successful invasive species in New Zealand because : 1) It has broad environment tolerance ; 2) It has generalist and opportunistic feeding habits , feeding not only on foliage , flowers and fruits , but also insects , bird eggs , nestling and fungi ; 3) It lacks competitors , unlike in Australia where some other marsupials also use tree holes and have some dietary overlap with possums ; 4) It lacks parasites and predators , compared with its native Australia ; 5) New Zealand forest ecosystems are generally more productive , higher in nutrients , and have fewer chemical defences than those in Australia ; 6) It had considerable human assistance involving multi-location releases around New Zealand.

Possums as pests

Damage by possums to native forests was not reported until the 1940's (Zotov ,1949) although the detrimental impact had been realized and debated much earlier (Payton , 2000). Possum damage varies widely depending on forest type (Zotov , 1949 ; Holloway , 1959 ;

Wardle , 1974 ; Dale & James , 1977 ; Pekelharing , 1979 ; Veblen & Stewart , 1982). Where preferred foods such as southern rata and kamahi are dominant , the selective browsing of possums may lead to complete canopy collapse (Meads , 1976 ; Batcheler , 1983). However the principle effect of possums on native forest is to cause gradual , consistent compositional changes (Coleman *et al.* , 1980 ; Green , 1984 ; Campbell , 1990 ; Payton , 2000 ; Nugent *et al.* , 2001).

Possums have recently been found to prey on native fauna in New Zealand (Brown *et al.* , 1993). They prey on eggs and nestlings of native birds such as kokako (*Callaeas cinerea wilsoni*) (Brown *et al.* , 1993) , kiwi (*Apteryx* spp.) (McLennan *et al.* , 1996) ; saddleback (*Philesturnus carunculatus*) and kereru (*Hemiphaga novaeseelandiae*) (Brown *et al.* , 1993). Also found in possum diet are land snails (*Powelliphanta* spp.) (Meads *et al.* , 1984) and other invertebrates such as stick insects (*Phasmatodea* spp.) , weta (*Stenopelmatidea* , *Rhaphidophorioae*) etc. (Cowan & Moeed , 1987). Possums were also suspected of competing with native birds by dietary overlap (Fitzgerald , 1984 ; Cowan , 1990b ; Cowan & Waddington , 1990). However , no studies have demonstrated actual competition , and whether there is an effect of competition on native birds remains unclear (Sadleir , 2000).

Possums are now considered to be the primary wildlife reservoir of bovine tuberculosis (Tb) in New Zealand (Coleman , 1988 ; Coleman & Caley , 2000). Tb in wild possum populations was first recorded in 1967 (Ekdahl & Money , 1970) and is now widespread. Transmission of Tb among possums may occur from mother to young , adult to adult through mating , fighting or den sharing (Green & Coleman , 1987 ; Pfeffer *et al.* , 1994). Batcheler & Cowan (1988) reported that despite many years of Tb possum control , areas with infected possums in both the North Island and the South Island had increased. Such expansion continues to the present day (Coleman , 1988 ; Coleman & Caley , 2000). Dispersal of young infected possums is considered to be the major cause of such expansion (Cowan *et al.* , 1996).

Present control of possums in New Zealand

The strategy for possum control in New Zealand is eradication on some offshore islands with high conservation

values and control on the mainland to contain their numbers and mitigate their damage.

There are two major techniques , toxic and non-toxic , currently used in possum control operations. In New Zealand there are six toxicants currently registered for possum control :1080 (sodium monofluoroacetate) , cyanide , Cholecalciferol , phosphorus , Brodifacoum , and Pindone (Eason *et al.* , 2000). Among these , 1080 is the most commonly used ,both in aerial poisoning and ground-based poisoning (Morgan & Hickling , 2000). ly used non-toxic techniques include shooting and trapping , using mostly leg-hold traps and ‘ Timm’s ’ traps (Montague & Warburton ,2000).

Possums have been successfully eradicated from several offshore islands , including Rangitoto Island in Hauraki Gulf near Auckland (Miller & Anderson , 1992) and Kapiti Island near Wellington (Cowan , 1992)(Fig. 1). However ,although the possum numbers have been contained by intensive control to protect native rare species and to mitigate the Tb infection in some areas ,their distribution on the New Zealand mainland has expanded in the past 15 years (Clout & Ericksen ,2000)(Fig. 1). In many habitats they occur at densities up to 20 times those in their native Australia (Cowan ,1990a).

Fig. 1 Distribution of possums in New Zealand at different stages (After Clout & Ericksen , 2000)

Why are conventional controls not effective ?

There are some disadvantages associated with current possum control methods. Firstly , they are costly. The frequency and scale of control operations are limited by financial resources. About NZ \$ 45 million is spent annually on possum control using poisons and trapping (Morgan & Eason , 1996). The cost for aerial poison drop operations ranges between NZ \$ 20 and NZ \$ 30 per hectare , and for ground-based poisoning and hunting operations between NZ \$ 5. 3 and NZ \$ 22. 6 per hectare.

Secondly , the efficacy of control operations has been affected by " aversion " behaviour of possums to toxins induced by sub-lethal dosing (Hickling *et al.* , 1999).

Thirdly , efficacy of conventional control methods is affected by population recovery after the control operation. Possums re-invade a controlled area and without further management , the population will recover through a combination of immigration , breeding by survivors and recruitment of their young (Clout , 1977 ; Green , 1984 ; Green & Coleman , 1984 ; Brockie *et al.* , 1997 ; Cowan *et al.* , 1997 ; Cowan & Clout , 2000).

Biological control of possums

Biological control is commonly considered to be the only long-term cost-effective solution to possum problem in New Zealand (Jolly ,1993 ;Cowan ,1996).

Approaches to biological control include investigating parasites and diseases that might reduce possum numbers and methods that attack key physiological processes (Cowan ,2000). Research is currently underway to identify and assess the impact of parasites , bacteria and viruses in possum populations (Heath *et al.* , 1998 ; Meers *et al.* , 1998). However , more work is needed to define their potential as biological control agents (Cowan , 2000).

Recent advances in molecular biology are being applied to the development of genetically engineered methods for biological control of possums (Cowan , 2000). Research into attacking key physiological processes includes interference with :

1) Fertilisation : immunisation against proteins from sperm and eggs so that fertilisation will be blocked (Duckworth *et al.* , 1998) ;

2) Embryonic development : immunisation against extracellular matrix proteins from the developing em-

bryo , coat proteins produced by the reproductive tract , and a factor (LIF) important for implantation that will result in death of the embryo (Selwood *et al.* , 1998) ;

3) Post-natal development : immunisation against proteins essential for sex differentiation (Deakin *et al.* , 1998) or the normal development of the ovary or testis , so that possums will be born sterile (Eckery *et al.* , 1998) .

4) Central endocrine control of reproduction : destruction of pituitary cells controlling the secretion of sex hormones or immunisation against sex hormones to inhibiting breeding (Eckery *et al.* , 1998) ;

5) Passive immunity : immunisation against a gut immunoglobulin receptor to prevent development of passive immunity to reduce survival of young (Eckery *et al.* , 1998) ;

6) Lactation : immunisation against milk proteins or regulating factors to reduce pouch young survival , or enhance the transfer of antibodies that will disrupt normal development (Demmer *et al.* , 1998) .

Biological control is considered to be a clean , humane and cost-effective method that can overcome problems associated with conventional control such as non-target kill , poison shyness etc.(Cowan , 2000) . Biological control by itself is not likely to eradicate possums from New Zealand , but by combining it with conventional methods there maybe potential for local or national eradication of this pest (Cowan , 1996 ; Bayliss , 1999 ; Cowan , 2000) .

Will biological control work ?

Ecological modelling by Barlow (1977) of a sexually transmitted possum-specific virus that induces permanent sterility without suppressing reproductive cycles , indicated that the percentage of females sterilised and the contact rate between individuals are major factors affecting the success of such a biological control. Possums are solitary nocturnal animals. Contacts between adult individuals are mainly through mating , fighting , and co-denning behaviour (Caley *et al.* , 1998) . Recent studies through minisatellite DNA profiling (Sarre *et al.* , 2000) and microsatellite DNA profiling (Taylor *et al.* , 2000) indicate that possum mating system is polygynous , with many males siring no young and some being more successful. This mating pattern does not change significantly when density is greatly reduced (Ji *et al.* , 2001) (Fig. 2) .

These findings imply that a virus-vectored sterilising agent is likely to spread between individual pos-

sums relatively rapidly and the rate of spread is not likely be affected by reductions in density.

Fig. 2 Mating patterns of brushtail possum of low and high density populations in New Zealand , expressed by number of young sired by males (Ji *et al.* , 2000) .

Fig. 3 Numbers of mature possums captured before and after sterilisation of females at two study sites , Coatesville and Huapai. P values of Chi-square tests on numbers of males and females (assuming 1 : 1 sex ratio) are shown above each data series : < 0. 1 = $P < 0. 1$; * = $P < 0. 05$; * * = $P < 0. 01$. (Ji *et al.* , 2000)

Another recent study investigated the short-term response of possums to female sterility by imitating female sterility from immunocontraception by tuballigation (Ji *et al.* , 2000) . A higher proportion of males was recorded in the study area after the sterilisation treatment (Fig. 3) . This appears to be caused by the surrounding males moving into the study area in the presence of sterilised female which keep cycling beyond the breeding season. Male body condition is significantly poorer in the post-mating season after the sterilisation. These results have some positive implications for successful transmission of an infectious immunocontraceptive agent : 1) Females sterilised by such an agent could potentially infect not only local males ,

but also those from immediately surrounding areas. However , the radius of effect is unlikely to be very large since no more unmarked adult males than normal were attracted to the treatment zone ; 2) Poor body condition is generally known to result in increased risk of mortality among mammals (Hanks , 1981 ; Fryxell , 1987 ; Gorden *et al.* , 1988 ; Choquenot , 1991). The reduced condition of male possums in 1997 , when sterilised females were present , was presumably due to sexual activity continuing into the winter months. If this reduced condition resulted in a higher male mortality risk during winter , the effect would be similar to the " vector induced mortality " of a biological control programme (Barlow , 1994) , although it would be caused indirectly and would be sex-specific.

Conclusions

The brushtail possum is one of the many introduced mammals that cause servere damage to native ecosystems and the economy of New Zealand. With conventional control methods such as poisoning , trapping and shooting , possums have been eradicated from some offshore islands and their numbers have been reduced in some areas of native forests on the mainland with high conservation value. However , the distribution of possums as whole on the mainland is expanding. Biological control , especially immunocontraception targeting female fertility has being investigated as more efficient and humane option for addressing the possum problem in New Zealand. A disseminating biological control , either traditional biocontrol using diseases or parasites , or biotechnological biocontrol such as fertility control through immunocontraception , depends on contact between possums for spread of a control agent (Barlow , 1994 ; Jolly , 1993). Recent studies showed that the polygynous mating pattern is not significantly affected by density reduction. This suggest that the spreading a biological control agent through sexual contact is likely to be maintained after density reduction , either by conventional control or by biological control itself. The attraction of surrounding males to sterile females indicates that female sterility is not likely to reduce sexual contacts between possums. This , together with the density-independent polygamous mating pattern and dispersal behaviour (Ji *et al.* , 2001) , makes the use of sexually transmitted immunocontraception a promising approach for future possum control.

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新西兰的负鼠——一场尚未完结的与外来入侵有袋类的较量

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摘要 : 为发展毛皮工业 , 新西兰 19 世纪中叶从澳大利亚引入刷尾负鼠(*Trichosurus vulpecula*) , 后成为新西兰一大害兽。刷尾负鼠不仅因破坏当地植被、捕食鸟蛋等而严重影响了新西兰的生物多样性 , 而且因其传播结核病菌对当地畜牧业造成了很大损失。新西兰每年花费巨额资金来控制这一害兽。虽然刷尾负鼠在一些孤立的岛屿和重点自然保护区已完全被消灭或得到有效的控制 , 但在新西兰大部分地区其分布却还在扩展 , 依然威胁着新西兰的生物多样性和农牧业生产。传统的控制方法包括兽夹捕杀、射杀和药物灭杀 , 其效果不佳的主要原因是 : 1) 受资金的限制 2) 小面积控制后因为种群密度减小 , 负鼠的生育率、存活率随之增高。加上新个体从周围迁入 , 种群数量迅速恢复。生物防治特别是免疫绝育法被认为是经济、人道及有效的方法。新的研究结果证明刷尾负鼠具有一雄多雌的繁殖方式 , 而且在雌兽被绝育后 , 种群中雄兽与雌兽之比率反而增高。因此雌兽绝育可能不会降低雌雄负鼠之间的接触频率。这些研究结果表明免疫绝育控制刷尾负鼠是很有前景的。

关键词 : 刷尾负鼠 , 入侵有袋类 , 生物防治 , 新西兰

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