POHUTUKAWA (*METROSIDEROS EXCELSA*) HEALTH AND PHENOLOGY IN RELATION TO POSSUMS (*TRICHOSURUS VULPECULA*) AND OTHER DAMAGING AGENTS

GORDON HOSKING and JOHN HUTCHESON

New Zealand Forest Research Institute,
Private Bag 3020, Rotorua, New Zealand

(Received for publication 26 January 1993; revision 30 June 1993)

ABSTRACT

The impact of possums (*Trichosurus vulpecula* Kerr.) and insects and disease on the canopy development of pohutukawa (*Metrosideros excelsa* Gaertn.) was studied at Homunga Bay on the Coromandel Peninsula. Possums were the only threat to established trees through damage to foliage and vegetative buds. The study also showed that regeneration occurred rarely because of the presence of feral goats and domestic sheep and cattle. It is recommended that possum control be carried out in late winter so as to protect new vegetative buds, and that fencing out of domestic stock to allow regeneration be done where possible.

Keywords: canopy development; coastal forest; possum damage; insect damage; *Trichosurus vulpecula* ; *Metrosideros excelsa.*

INTRODUCTION

In the late 1980s increasing public concern at the deterioration of pohutukawa in Northland, and the suggestion that insects might be responsible, prompted the Department of Conservation (DOC) to commission the Forest Health Group of the Forest Research Institute (FRI) to carry out a problem analysis. This analysis involved an aerial survey of the coast and inshore islands of the northern half of the North Island. Stands were identified and a visual assessment of their condition made. Aerial inspection was followed by ground inspection and assessment of 197 individual sites. The results (Forest Research Institute 1989) suggested that present stands represent only a fraction of the original pohutukawa resource, that possum browse was causing serious damage on certain sites, and that the resource was dominated by old stands with very limited natural regeneration occurring.

Despite the very special place pohutukawa has in the psyche of New Zealanders and its characteristic place in the northern coastal flora of New Zealand, little has been published describing its ecology and phenology. The only book on the species (Conly & Conly 1988) provides an excellent account of its historical and cultural significance but only a brief appendix of its botanical status. A number of papers (Cranwell 1981; Esler 1978; Nicholls 1963; Wright & Cameron 1988; Wise 1970; Hamilton 1959; Clarkson *et. al.* 1989; Hutcheson 1992) make reference to pohutukawa as part of particular areas of coastal or island vegetation but none discuss its biology or ecology in any detail. Unpublished reports on Scenic Reserves, such as those on Maunganui Bluff by A.E.Esler (Botany Division, DSIR) and P.Thomas (DOC), and on Ohope by S.M.Beadle & W.B.Shaw (DOC) contain only information on local distribution of the species. Hybridisation between pohutukawa and northern rata (*M. robusta* A.Cunn.) was described by Kirk (1899), Carse (1927), and Oliver (1928), and was investigated by Cooper (1954), but again these writers included little ecological discussion. The most detailed information on the ecology and phenology of pohutukawa is contained in two M.Sc. theses (Skeates 1980; Olds 1987). Both studies dealt with the effects of possums but were very specific in their particular objectives, were carried out on single sites, and were based on infrequent sampling. They did, however, present a great deal of new and valuable information, particularly that by Skeates (1980).

One of the recommendations made by Hosking and his co-workers (Forest Research Institute 1989) was that a study be initiated to examine the impact of possums, as well as insects and disease, on the pohutukawa canopy. The primary objectives were to investigate the impact of possums, clarify the relative importance of other damaging agents, and identify critical points where management action would be most effective.

STUDY SITE

The proposal for intensive study of the relationship between damaging agents and the decline of pohutukawa placed certain constraints on site selection. Ready access from Rotorua was essential to allow continuity of sampling. A population of several hundred pohutukawa of all age-classes was also required. Most importantly, the range of health problems and crown damage observed in the nationwide survey needed to be present. It was also considered that it would be advantageous if the site was one administered by the Department of Conservation (as a scenic reserve, for example) so that essential site operations such as tree banding and erection of traps could be carried out.

The site chosen, the Homunga Bay Block of the Orokawa Scenic Reserve, was first identified in the aerial survey as the closest significant area of pohutukawa exhibiting severe canopy damage. Much of the 114-ha block was covered by coastal forest dominated by pohutukawa and rewarewa (*Knightia excelsa* R.Br.) with significant elements of miro (*Prumnopitys ferruginea* (D.Don) de Laub.), rimu (*Dacrydium cupressinum* Lamb.), hinau (*Elaeocarpus dentatus* (J.R. et G.Forst.) Vahl, and northern rata on the inland parts of the reserve (Miller 1984). Subcanopy and groundcover plants had suffered from the heavy browsing of goats, sheep, and cattle which had occurred throughout the reserve. The pohutukawa component was dominated by very large mature and overmature trees, but there was also a good representation of sapling and juvenile trees. The reserve did not have high public usage, which increased the security of equipment, and it had the added advantage of an excellent botanical survey carried out by Miller (1984) from which the vegetation sketch map (Fig. 1) is taken.

The population assessment of the wider stand included sample trees from up to 500 m from the coast, while the 12 study trees selected were spread across the grassy terrace and colluvial slope up to approximately 300 m from the shore.

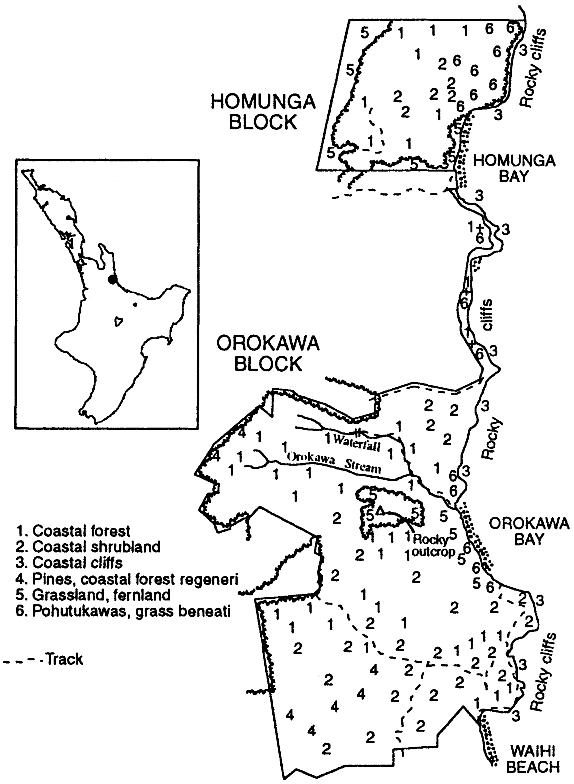

FIG. 1–Location of Homunga Bay Block in Orokawa Scenic Reserve (from Miller 1984)

METHODS

Population Characterisation

A representative sample of 102 pohutukawa, being all those included in an approximately 20-ha area of sea cliff, terrace, colluvial slope, and ridge, in the eastern half of the Homunga Bay Block were characterised as follows. Measurements, or estimates, were made for height, bole height, crown area, and dbh, and trees were categorised into the life stages seedling (1), sapling (8), juvenile (13), mature (31), overmature (35), senescent (12), and rejuvenated (2). From trial increment corings pohutukawa trees were virtually impossible to age owing to poor definition of growth rings, wood hardness, and the presence of internal rots; however, distinct life stages were easily characterised and may have more biological relevance than the passage of years. Seedlings included all stages from seed germination to small multi-stemmed bushes usually supported on tree fern (particularly in grazed areas), while saplings often had a single stem and a well-developed crown up to 3 m across. The juvenile phase is characterised by vigorous growth, with rapid canopy expansion and accelerated height growth producing a deep somewhat-conical crown. At maturity the crown assumes the more typical umbrella-like shape which may extend over 700 m^2. With over-maturity and senescence, crown contraction and thinning occur with eventual dieback of large limbs. Many examples were found where breakage or collapse of large limbs or the main bole, and subsequent rooting of the fallen section, had resulted in a reversion of the limb or the tree to the juvenile phase of growth.

Crowns were scored on a 1 to 5 scale for each of the following variables: size; density; contraction; projections; flush; flowering; epicormic shoots; damage by possums, insects, fungi; dead terminal shoots; twig breakage; and foliage abscission. Contraction of the crown was recognised from the extension of large dead branches beyond the present canopy, and projections were defined as vigorous growth (usually single branches) beyond the hemispherical outer canopy. The scale was non-linear (1=0, 2=1–25%, 3=25–75%, 4=75–95% and 5=95–100%). The position of each tree was described in terms of its topography, vegetation, and aspect. These population data are presented in summary form only in this paper.

Sample Tree Monitoring

Twelve trees were selected for intensive monitoring of the impact of insects, diseases, and possums on the crown, and for documenting the phenology of crown development. The major constraint on the selection of these trees was the need for them to be isolated from adjacent crowns so that possums could not jump directly into them. This limited the number of trees available, and also the study site, to the grazed terrace area adjacent to the shore, where cattle had browsed the base of all canopies beyond possum jumping range.

The sample trees included two saplings, six juveniles, and four old trees, of which one sapling, two juveniles, and one old tree were protected from possum damage by metal bands. A single funnel-shaped litter trap with a catching area of 0.283 m^2 was suspended beneath the canopy of each sample tree to collect material falling from the crown. Litter traps have been used for studying insect biologies (e.g., Morris 1949; Hosking & Hutcheson 1987) and also seed production in New Zealand forests (e.g., Beveridge 1965). Results are expressed on a unit area basis as a mean of all trees sampled. At fortnightly intervals each tree crown was scored, using the 5-point scale, for the following variables: bud, flower, and foliage development; damage by possums, insects, and disease; loss of foliage, buds, and seed pods; twig breakage. Litter trap collections were sorted into leaves, buds, twigs, and possum pellets, and leaves were sorted by age and damage types. Sampling was begun on 5 May 1989 and concluded on 18 April 1991, giving two complete years of data.

Treatment of Data

No attempt was made to replicate samples to the level required for rigorous statistical analysis. Such replication would have been impossible without major stand modification to isolate individual tree canopies. The primary objective of the study was to identify gross seasonal patterns and impact of damage, so that management imperatives could be addressed and a focus provided for more rigorous studies in the future. This objective dictated a broad approach while the pragmatics of intensive assessment constrained the sample size. We have therefore followed the advice of Hurlbert (1984) and accepted the lack of replication as the only option while resisting the temptation to give the data an "unmerited veneer of rigor" through the application of inappropriate statistical methods. Data are therefore presented in graphical form, based on simple means for either all protected or unprotected trees or the whole population, and subjected to the MINITAB smoothing procedure based on running medians.

RESULTS

Population Characteristics

Seedlings are virtually absent from the Homunga Bay site except for scattered individuals which have germinated on the side of tree ferns above the reach of cattle, sheep, and goats. The presence of domestic farm stock and feral goats has had a profound influence on the plant community, with little regeneration of any tree or shrub species at ground level within the most heavily grazed areas. Along the coastal part of the site grassland prevails, often extending well back into the relatively open forest. Vigorous saplings and juvenile trees are common along the sea cliff and up the steep stream washes, and are also found scattered through the grassland. The forest is generally dominated by mature and old trees, many with contracting crowns supported by massive branches and trunks. The total population of pohutukawa in the Homunga Bay Block is estimated at over 1000 trees. The population sample described here is believed to be broadly representative of this population.

The basal area of 70% of the 102 sample trees was less than 1 m^2, with only three exceeding 4 m^2 and the largest assessed being 7 m^2. Crown spread was highly dependent on tree form and life stage with some specimens exceeding 700 m^2 but most being less than 300 m^2.

Very few trees had what was considered a normal crown density, with most displaying considerable thinning of foliage. Almost a third of the trees showed no crown contraction (as characterised by the projection of dead branches) and these were mainly vigorous juvenile trees, with virtually all mature and old trees showing some evidence of retrenchment. A few trees showed a degree of contraction that affected almost all secondary branches and limited the crown to a small fraction of what could be expected. Both crown thinning and crown contraction were related to severe and prolonged possum damage. Only four trees showed no obvious possum damage while over 70 were rated as having moderate to severe damage. In general, it could be assumed that almost all pohutukawa trees in the Homunga Bay area were suffering damage by possums.

Canopy Development and Phenology

Vegetative bud expansion began in September with a peak of swelling buds on the tree in late November-early December (Fig. 2a). Although bud burst and shoot expansion were evident on individual trees throughout the year, the peak of activity was concentrated in December and January. Flower buds develop concurrently with vegetative buds and became distinguishable in early December. Flowering at Homunga Bay occurred in late December and early January and immature seed capsules were formed by late January and February. Most shoots flushed in December and January, with a secondary period of activity in late April and early May (Fig. 2b). This secondary flush was strongest on trees which had flowered heavily during the previous summer or those which had suffered particularly severe possum damage.

From the growth patterns of leaves on trees, coupled with the observed pattern of spring and autumn flushes, it was estimated that young vigorous pohutukawa may retain undamaged foliage for up to 3 years, with occasional leaves being held even longer; however, the bulk of old foliage is lost from the tree within 2 years of its production. Old leaves are shed throughout the year, loss of old foliage being lowest during the late winter and early spring

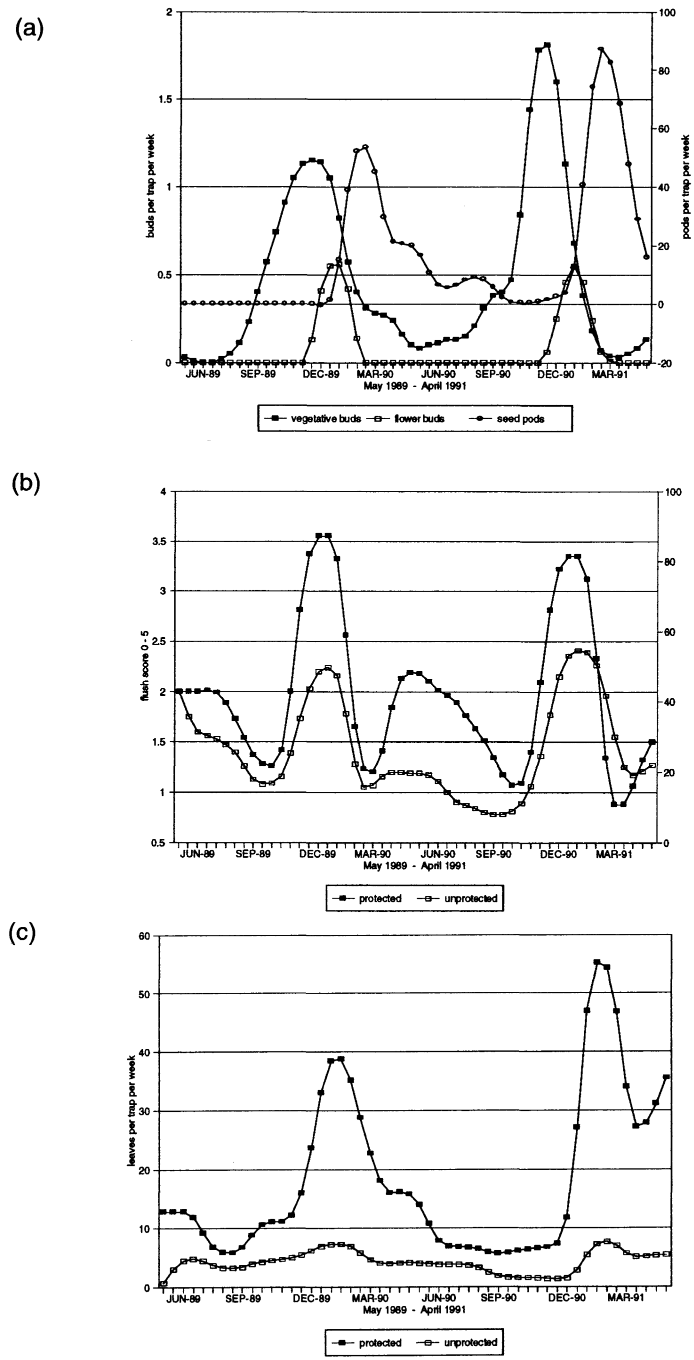

FIG. 2–Seasonal patterns of canopy development for pohutukawa at Homunga Bay: (a) bud and seed capsule development; (b) new foliage production scored as 0 (none) to 5 (all shoots) for protected and unprotected trees; (c) old foliage shed from protected and unprotected trees.

and a strong peak occurring in February after the expansion of new foliage (Fig. 2c). Unprotected trees at Homunga Bay had very little undamaged mature foliage, but this was shed in the same pattern as that from protected trees (Fig. 2c). Loss of dead twigs and small branches also showed a seasonal peak in late winter/early spring but this was more probably related to wind than to any seasonal biological activity of the tree.

Insects and Disease

The majority of old leaves showed some evidence of insect damage although it usually affected only a small part of their total surface area. The pattern and magnitude of the loss of old leaves with insect damage was similar for both protected and unprotected trees. Seasonally, but only on a few trees, foliage was extensively browsed by chrysomelid and/or scarabaeid beetles, and occasionally phasmids caused noticeable damage. Over the whole pohutukawa population, insect damage to mature and old foliage was low.

The most significant damage to pohutukawa from any insect species was the loss of newly expanded foliage caused by the small native weevil *Neomycta rubida* Broun. The adult insects "maturation feed" (i.e., feed until sexually mature) on the developing flush, damaging the leaves in a "shothole" fashion. Females then lay usually one egg close to the leaf base and the larvae mine in a linear fashion, often along a side vein. The young leaves are abscissed and the insect completes its development in the leaf on the ground. There appear to be two generations, similar to those found by Hosking & Hutcheson (1986) for *N. pulicaris* attacking hard beech (*Nothofagus truncata* (Col.) Ckn.), the main one occurring in spring and a smaller one in autumn coinciding with the main foliage flushes of the tree (Fig. 3). Heavy infestations appear to be concentrated in the lower third of the crown and can occur on particular trees whose phenology coincides with the weevil's development. Weevil populations are thereby maintained at a moderate level, affecting only a part of the pohutukawa population in any given year. In some circumstances, however, particularly where older trees

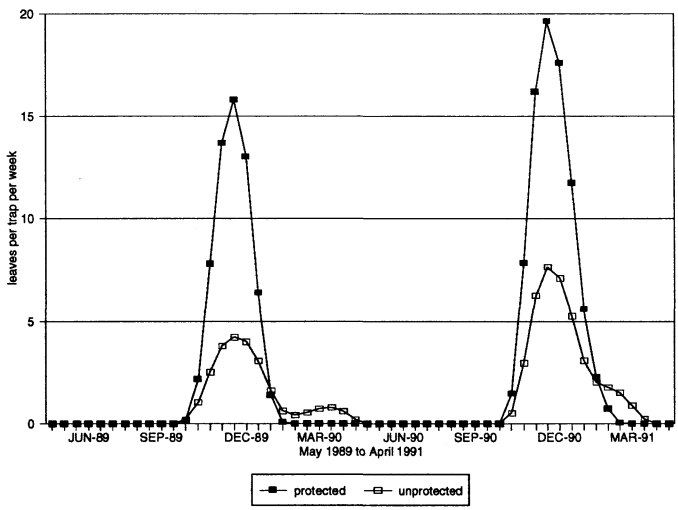

FIG. 3–Leaves infested by the leafmining weevil *Neomycta rubida* collected fortnightly from litter traps.

have had foliage buds heavily browsed by possums, heavy weevil infestation on the few remaining shoots of the tree may contribute to tree decline. The difference in leaf shedding between protected and unprotected trees (Fig. 3) reflects the availability of new foliage for attack. Trees heavily browsed by possums lose most new buds and produce very limited flush. They do, however, produce a limited secondary flush which also sustains *Neomycta rubida* attack (Fig. 3). If the tree is vigorous and in good health, even heavy infestations of the weevil do not appear to cause appreciable damage. Parasitism of the weevil larva by a small wasp (Braconidae, cf. *Doryctes* sp.) may be as high as 50% in late November.

The wilting of newly expanding shoots also appeared dependent upon individual tree phenology. Many wilted shoots were damaged by larvae of the weevil *N. rubida* and the tortricid moth *Ctenopseustis obliquana* (Walker). Up to 30% of wilted developing shoots contained gregarious larvae of tiny gall midges (Cecidomyidae). Larvae were enfolded between the terminal leaves at the tips of the wilted shoots, but no causal relationship was demonstrated with the shoot wilt. In addition, isolations made from shoots in which the wilt was not immediately attributable to insect damage consistently yielded a *Dothiorella* sp. fungus which is also a candidate as a causal agent. Low levels of wilt occurred throughout the year and peaked, as would be expected, at the time of maximum flush. Generally, replacement flush ensured the effect on the tree was minimal.

Effects of Possums

Foliage damage by possums is highly characteristic and easily separated from that of insects, primarily by the torn leaf blade and often protruding stripped midrib. Old foliage damage was assessed from material collected in litter traps and from an assessment of damage to foliage on the tree. Foliage damaged by possum chewing (Fig. 4a) was shed in the same seasonal pattern as undamaged foliage (Fig. 2c). However, a comparison of protected and unprotected trees (Fig. 4a) suggested possum-damaged leaves are not retained on the tree for the 2 years typical of undamaged leaves. Trees protected in May 1989 yielded less than half the number of possum-damaged leaves compared to unprotected trees at peak shedding in January 1991. The proportion of old foliage showing damage on the trees decreased sharply for protected trees in 1990 although possums successfully invaded two protected trees for short periods, producing some damage (Fig. 4b). Very little undamaged foliage was shed from unprotected trees (Fig. 2c).

Possums fed voraciously on the expanding vegetative buds in spring. While consuming a large proportion of buds they damaged many more which were then abscissed from the tree, appearing in litter trap material. Some trees lost almost all buds through feeding and damage, the possum often damaging the second of a vegetative bud pair while consuming the first. Very little damage was recorded to flower buds although severely damaged trees rarely flowered, in contrast with the protected old tree which flowered profusely each summer.

The seasonal pattern of abscissed vegetative buds taken in litter traps, and the damage score for buds on the tree (Fig. 5) are in close agreement for both primary and secondary flushes, although on-tree damage naturally precedes trap catches.

DISCUSSION

There is a large community of insects associated with pohutukawa, most of which are endemic and several of which have evolved a very close relationship with their host

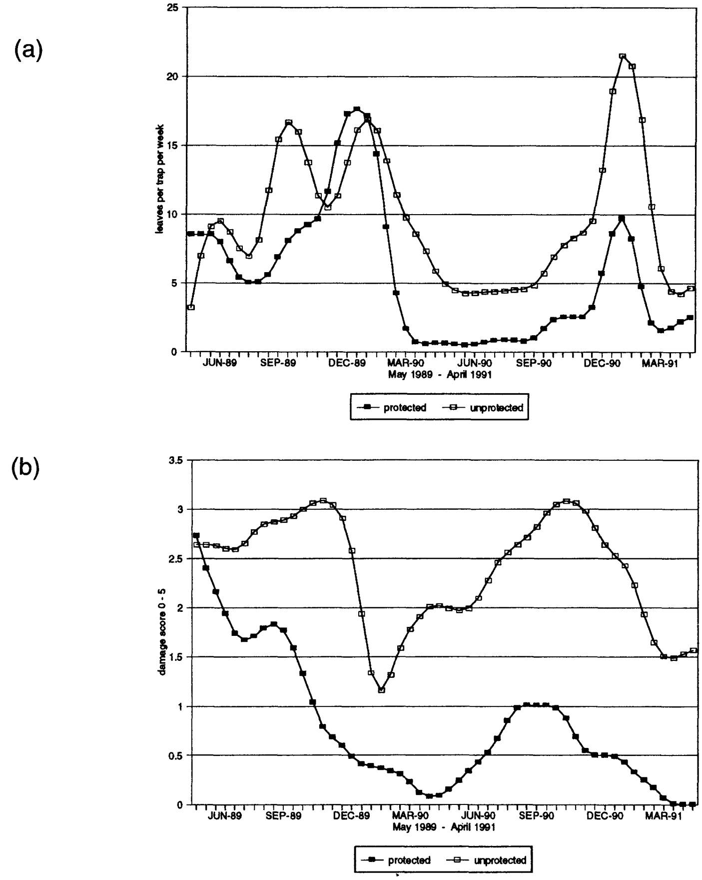

FIG. 4–Possum damage to old foliage for both protected and unprotected trees (a) shed leaves from litter traps, and (b) on the tree scored as 0 (none) to 5 (all).

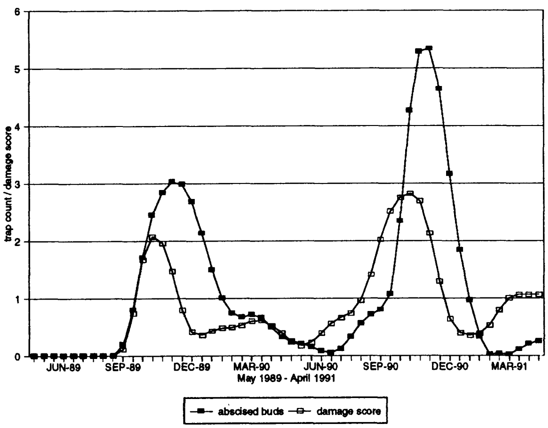

FIG. 5–Abscissed vegetative buds collected in litter traps under unprotected trees, and on-tree bud damage graded from 0 = none to 5 = all expanding buds.

(Hutcheson unpubl. data). This is true also for other *Metrosideros* sp. (Hoy 1958). Diseases have not been well documented, although a number of leaf spot and saprophytic fungi have been recorded. The only disease commonly found in the course of this study was a presently unidentified *Dothiorella* sp. fungus associated with the wilting of new shoots just after bud burst. Similar damage was also associated with a gall midge (Cecidomyidae) but the cumulative effect of this insect and the wilt fungus is unlikely to be of any significance to tree health. Many wilted shoots were also damaged by larvae of the weevil *N. rubida* and of the tortricid moth *C. obliquana*, but once again damage appeared inconsequential to tree health.

Substantial variation in phenology was recorded within the study site, but patterns and timing of main events appeared broadly characteristic of pohutukawa throughout the species' natural range. Between-tree variation of both phenology and physiological characteristics at particular sites has been recorded by other authors (Skeates 1980; Olds 1987; Oliver 1928) and, as mentioned previously, hybridisation with *M. robusta* formed the basis of Coopers' (1954) study. This suggests individual populations of pohutukawa contain considerable genetic variation, a strategy which makes biological sense when the extreme nature of the trees' habitat is considered. The resilience of this coastal buffer vegetation is further enhanced by the ability to continually replace apical growth with lateral growth when the dominant growth tip of a twig is damaged (Skeates 1980, and this study). These factors and others enable pohutukawa to withstand and continue to flourish through extreme climatic events and sporadic infestations by the endemic insect *N. rubida,* both of which can reduce the amount of foliage available for photosynthetic production.

The report on the health of pohutukawa prepared by the Forest Research Institute in 1989 identified possums as one of the primary threats to the future of the species and the only biological agent threatening the health of mature trees. Meads' (1975) landmark study of northern rata had already documented the decline and death of mature trees subjected to 3 years or more of possum defoliation. The Homunga Bay study extended these earlier findings to pohutukawa and developed a strong focus on the relationship between possum damage and canopy development. The study's ultimate objective was to provide managers with a pest control strategy which would give greatest benefit to pohutukawa.

The study showed that it is the possum's habit of continued harvesting of the swelling spring buds that enables it to have such a significant long-term damaging effect on the tree. This harvesting of initial and replacement buds inevitably leads to crown contraction, death of twigs, and a huge reduction in foliage, and subsequent photosynthetic production in the following growing season. While possums were active in some unprotected trees throughout the year, activity and damage increased greatly in late winter and early spring. Newly flushed foliage was found to be unattractive and rarely browsed until hardening-off occurred, and so protection from possums for a short period during the spring flush leads to rapid refoliation. The present study also suggests that younger more vigorous vegetation is better able to withstand possum browse than mature and senescent trees. Payton (1983) showed similar differences in tolerance of old and young southern rata (*Metrosideros umbellata* Cav.).

During periods of high activity, possum runs or pads were clearly visible between trees as flattened tracks through the rank grass. All epicormic shoots on trunks and branches were browsed, with trees often forming callous growth at the shoot origin. Observations from other areas suggest that heavy possum browsing of the upper canopy may be associated with the initiation of epicormic shoots, and this study suggests that heavily browsed epicormic "clumps" are one indication of the need for possum control.

The present structure of the Homunga Bay coastal pohutukawa forest has been strongly influenced by the browsing of feral goats and domestic stock. Browsing by sheep and cattle from an adjacent farm, and by a resident population of feral goats, appears to have precluded all seedling establishment except as perching plants on tree fern stems. This accords with the survey results (Forest Research Institute 1989) which found that less than 15% of 190 sites examined had pohutukawa regeneration, and these were only those sites where domestic stock were denied access.

The collapse of coastal forest and its major pohutukawa component, such as that found in Homunga Bay, has implications well beyond the impact on pohutukawa itself. The flora and fauna of forest ecosystems are strongly integrated and so highly specific (Hutcheson in prep.) that severe modification or collapse threatens the wider biological community. Kuschel (1990), for example, clearly demonstrated the dependence of New Zealand's indigenous insect fauna on the retention of the natural habitat. The present study highlights the need for an integrated strategy both to control possums and to restore the integrity of the coastal pohutukawa forest.

CONCLUSIONS

Effect of Possum Browse

Possums are an immediate threat to the survival of mature and old pohutukawa trees at Homunga Bay and to the long-term development of young and juvenile trees. The most serious damage occurs with the harvesting of extending vegetative buds in the spring, often involving almost 100% of vegetative buds, although flowerbuds sustained only scattered damage. While newly flushed foliage is unattractive and rarely browsed, possums return to the trees in winter, feeding on mature foliage and appearing to cause premature loss of damaged leaves. Repeated severe possum damage on old trees leads to rapid crown contraction from the progressive death of fine twigs and small branches. It also reduces flowering and subsequent production of seed, probably through diversion of the tree's resources toward foliage replacement.

To obtain the most benefit to the pohutukawa, possum control should be carried out in late August/early September. This will protect new buds and allow the trees to complete new foliage production with resulting increase in photosynthetic production in the following seasons.

As the new foliage flush is relatively unpalatable to possums, even a short respite from possum activity over the bud extension/foliage flush period will result in significant foliage accumulation and resulting gains in tree vigour. If possum control results in protection for 2 years, trees may be able to regain their normal complement of canopy foliage.

Effect of Insects and Disease

While there are a large number of insects and an undetermined number of micro-organisms associated with pohutukawa, according to the Homunga Bay study neither singly nor cumulatively do they represent a threat to the health of the species. The leaf mining weevil *N. rubida* and shoot wilt associated with insects and the *Dothiorella* sp. fungus may contribute to the decline of specific very old trees which are also under severe pressure from possums.

Effect of Other Browsing Animals

Browsing by feral and domestic stock has not only had a dramatic impact on the recruitment of pohutukawa seedlings, but has also severely modified the whole coastal forest association, thereby compromising the integrity of the reserve. If allowed to continue, this would threaten the existence of many of the reserve's component species.

Note: Since this study was concluded, the Department of Conservation has fenced the Homunga Bay Block of the Orokawa Scenic Reserve and carried out a possum and goat control operation. The possum control was conducted in September, prior to main bud extension. Although the kill rate was low at approximately 70%, a great improvement in the pohutukawa canopy is already evident and subsequent flowering has dramatically increased. Recovery of pohutukawa, and regeneration of it and other forest species, are being monitored.

ACKNOWLEDGMENTS

We gratefully acknowledge the contribution of colleagues Margaret Dick for her work on fungal isolations, and Patrick Walsh, William Shaw, and Ian Payton in reviewing this manuscript. This study was funded jointly by the Ministry of Forestry and the Department of Conservation.

REFERENCES

BEVERIDGE, A.E. 1965: Durable seed traps. *New Zealand Forest Service, Forest Research Institute, Research Leaflet No. 9.*

CARSE, H. 1927: Botanical notes, with descriptions of new species. *Transactions of the New Zealand Institute 57*: 89–93.

CLARKSON, B.D.; CLARKSON, B.R.; SMALE, M.C. 1989: Appendix 1. Vegetation destruction and recovery following recent eruptions on White Island (Whakaari), Bay of Plenty, New Zealand. Pp 137–8 *in* Haughton, B.F.; Nairn, I.A. (Ed.) *New Zealand Geological Survey Bulletin 103.*

CONLY, G.; CONLY, M. 1988: "New Zealand Pohutukawa". Grantham House, New Zealand. 88 p.

COOPER, R.C. 1954: Pohutukawa × rata: variation in *Metrosideros* (Myrtaceae) on Rangitoto Island. *Records Auckland Institute and Museum 4(4)*: 205–12.

CRANWELL, L.M. 1981: "The Botany of Auckland". Auckland Institute and War Memorial Museum, Auckland, New Zealand.

ESLER, A.E. 1978: Botanical features of islands near the west coast of the Coromandel Peninsula, New Zealand. *New Zealand Journal of Botany 16*: 25–44.

FOREST RESEARCH INSTITUTE 1989: Tackling the pohutukawa health problem. *New Zealand Ministry of Forestry, Forest Research Institute, What's New in Forest Research No.178.*

HAMILTON, W.M. 1959: Vegetation. Pp. 62–9 *in* Hamilton, W.M.; Baumgart, R.L. (Comp.) "White Island". *Department of Scientific and Industrial Research Bulletin No.127.*

HOSKING, G.P.; Hutcheson, J.A. 1986: Hard beech *(Nothofagus truncata)* decline on the Mamaku Plateau, North Island, New Zealand. *New Zealand Journal of Botany 24*: 263–9.

———1987: Lepidopterous defoliators in a developing *Pinus radiata* stand. *New Zealand Journal of Forestry Science 17(2/3)*: 331–7.

HOY, J.M. 1958: Coccids associated with rata and kamahi in New Zealand. *New Zealand Journal of Science 1*: 258–80.

HURLBERT, S.H. 1984: Pseudo replication and the design of ecological field experiments. *Ecological Monographs 54(2)*: 187–211.

HUTCHESON, J. 1992: Observations on the effects of volcanic activity on insects and their habitat on White Island. *New Zealand Entomologist 15*: 72–6.

———Insect community characterisation using Malaise trapped Coleoptera from a vegetation succession in the central North Island, New Zealand (in prep.)

KIRK, T. 1899: "The Students' Flora of New Zealand and the Outlying Islands". Government Printer, Wellington. 408 p.

KUSCHEL, G. 1990: Beetles in a suburban environment: A New Zealand case study. *Department of Scientific and Industrial Research, Plant Protection Report No.3.*

MEADS, M.J. 1975: Effects of possum browsing on northern rata trees in the Orongorongo Valley, Wellington, New Zealand. *New Zealand Journal of Zoology 3*: 127–39.

MILLER, N.C. 1984: OROKAWA SCENIC RESERVE BOTANICAL SURVEY. NEW ZEALAND DEPARTMENT OF LANDS AND SURVEY.

MORRIS, R.F. 1949: Frass drop measurements in studies of the European spruce sawfly. *University of Michigan School of Forestry, Conservation Bulletin No.12.*

NICHOLLS, J.L. 1963: Volcanicity and indigenous vegetation in the Rotorua district. *Proceedings of the New Zealand Ecological Society 10.*

OLDS, C.B. 1987: Aspects of the ecology of the brush-tail possum on Rangitoto Island. M.Sc. Thesis, University of Auckland.

OLIVER, W.R.B. 1928: The New Zealand species of *Metrosideros* with a note on *Metrosideros collina* (Forst.) Gray. *Transactions of the New Zealand Institute 59*: 419–23.

PAYTON, I.J. 1983: Defoliation as a means of assessing browsing tolerance in southern rata *(Metrosideros umbellata). Pacific Science 37(4)*: 443–52.

SKEATES, J.K. 1980: The assessment of possum damage to pohutukawa. M.Sc. Thesis, University of Auckland.

WISE, K.A.J. 1970: The terrestrial fauna of White Island, New Zealand. *Records of the Auckland Institute and Museum 7*: 217–52.

WRIGHT, A.E.; CAMERON, E.K. 1988: Botanical features of north eastern Great Barrier Island, Hauraki Gulf, New Zealand. *Journal of the Royal Society of New Zealand 3*: 17–44.