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Figure 9 Madeira vine at Fishing Rock with large numbers of knobbly tubers and semi-succulent leaves, June 1993.

that they could be dispersed around the coast by sea, and establish new colonies if washed above the strand line. This is apparently the normal method of dispersal for this plant elsewhere in the Pacific (Sykes 1977b).

Like the other vines mentioned, Madeira vine is light demanding. At Fishing Rock it grows on a north-facing scree slope and is colonising the forest edge above the scree. Madeira vine is very tolerant of salt spray and grows in coastal locations in Rarotonga (Sykes 1977b). Although spread of the vine at the known locations will be predictable, tubers dispersing around the coast could result in infestations at a host of locations on Raoul, and the plant could also spread to the Meyers.

Whereas the leaves of Madeira vine are soft and susceptible to herbicides, the tubers are resistant. Regrowth of plants consistently occurs from tubers. Thus, the plant is very difficult to eradicate.

5.4.3 *Control methods*

Selby (1982d) and Sykes (1984) commented on the extreme resistance to herbicides that this species shows and suggested that physical destruction of the plants and tubers might be the only method of control. Ombler (1977) trialled Gramoxone paraquat, Tordon 520 Brushkiller and Tordon 2G granules on the Fishing Rock population and these appeared to kill all leaf and stem growth, but not the tubers. Tordon 50D was trialled by Dale (1979). Adlam (1979) treated one area at Fishing Rock with sulphuric acid and undiluted Weedazol TL and trialled Actazine 80 and Simazol 4A but none of these treatments were successful. A further trial with caustic soda apparently caused the breakdown of tubers into a jelly-like substance (Adlam 1979). It was suggested that Roundup (1%) and Weedazol (2%) be trialled for their

effectiveness at controlling Madeira vine (Anon. 1985). Gardner (1988) sprayed 50 m^2 at Bell's Ravine, although it is not stated which herbicide was used.

In 1991, Clapham used Escort on the infestation at Bell's Ravine, and part of the Fishing Rock infestation. He found that Escort didn't kill the tubers and suggested that the best way of limiting the spread of this plant would probably be to spray the fringes and remove the tubers by hand (Clapham, 1991b). Crawley (1991 a) reported that Am mate XL killed only small patches of Madeira vine. Clark (1992) found that the plant at Bell's Ravine could be controlled by sheer persistence but at Fishing Rock the site is large and very steep and much more difficult to control. He could find no practical way to kill the tubers. Samson (1993a) sprayed the Madeira vine at Fishing Rock with Escort and Landmark and neither herbicide was effective. Fastier (1994) trialled the following herbicides on 2 x 2 m plots of the vine at Fishing Rock: Animate, Roundup, Velpar, Escort, 2, 4 D, and Tordon D5 and 2G granules. All poisons seemed to be ineffective. Whereas some of the vines wilted the tubers were not affected by any of the herbicides used.

Many different herbicides have been trialled in an effort to kill Madeira vine. However, the resistance of the tubers leads to continued growth. The leaves and stems of the parent plant are killed but new growth sprouts from the tubers.

Manual removal of tubers from the site appears to be the only option for eradication. Tubers should be collected into sacks and then burnt or covered in thick black polythene to enhance rotting. Tubers which are jammed in rock crevices could be damaged with crowbars and have herbicide applied. Alternatively, they could be marked and any new foliage repeatedly removed, either manually or with herbicide, until the reserves of the tuber are used up.

Thus, a suggested procedure for eradication is:

1. Rig up security lines at the Fishing Rock site.
2. Spray the infestations at Fishing Rock and Bell's Ravine with Escort or Roundup to knock down the foliage and stems.
3. Remove all accessible tubers by hand, gathering them into sacks and taking them back to the Hostel for destruction in the fire pit.
4. Mark the locations of all tubers lodged in rock crevices or buried too deeply to remove safely and persistently spray or remove by hand all regrowth which sprouts from the tubers. Eventually, the reserves in the tubers should be exhausted if the regrowth is removed before it has translocated food to the tubers.
5. Record the success (or otherwise) of this method to enable a change of approach if this is not working.

5.4.4 Future work

It is imperative, given the difficulty of killing this species, that the relatively small infestations currently on Raoul be eradicated. Since the tubers are resistant to herbicide, it is highly likely that they are resistant to salt water also. Therefore, it is only a matter of time before the tubers which roll down the scree slope at Fishing Rock fall into the sea and are dispersed around the coast.

mechanism by which the Fishing Rock infestation established because this plant was known only from Bell's Ravine in 1967.

Manual eradication of this species has been suggested as the only effective method since 1984. The seriousness of the threat that this species poses should not be underestimated and physical removal of the tubers must be commenced immediately. While the method suggested might seem daunting and tedious, it is an untried option and should be attempted now before the scale of the problem becomes larger and eradication becomes even more difficult.

5.5 *Psidium cattleianum* – PURPLE GUAVA

Previously *Psidium littorale*

5.5.1 History

Cheeseman (unpub.) records purple guava as a crop grown by Bell in 1887. In 1944, Sorensen noted several trees of what he tentatively called red guava in Denham Bay and stated that there was no sign of fruit on them. However, since he photographed purple guava from the northern side of the Island, but called it yellow guava, it is possible that his record of purple guava from Denham Bay is incorrect. Sykes (1977a) did not record purple guava from Denham Bay, so it seems likely that it was never grown there, although Sykes (1990) mentions a report of it from the south-east end of Denham Bay.

The main localities for purple guava are Low Flat through to the Orchard behind the Meteorological Station (Sykes 1977a) and further west to the ridges above the Woolshed, the crater near Blue Lake and Tui Lake and near the Fishing Rock road junction (Fastier 1994).

Purple guava has never been recorded naturalising in large numbers on Raoul, although it has spread into the crater in the last 20 years. Given its invasive behaviour on other Pacific Islands, it is prudent to eradicate this species before it does disrupt the forest ecosystem on Raoul. Eradication of purple guava began in 1973 and by 1980, as a result of the work done, Sykes (1980) could not find the species growing on Raoul in November 1980. However, he advised vigilance with regard to this species. When Sykes next visited Raoul, in October 1984, he found quite a few plants, some of which were too large to pull out. Also a single flowering tree was found in the Dry Crater by Tui Lake, a considerable distance from previously known sites (Sykes 1984). Bracefield (1987) killed 99 "guava", species not specified, mainly from near the Woolshed. Gardner (1988) killed 302 purple guava, mainly from the Orchard. In October 1990, 82 plants were killed in the area between Denham Bay track and Bell's Ravine (Crawley 1990). In 1990, plants were found in the Orchard and by Boat Cove Road (Sykes 1990). Clapham (1991 a) killed 15 purple guava in the Dry Crater and 172 "guava" less than 1 m tall, most probably this species as it is the more common. In 1994 purple guava was found along the lower northern slopes of the Island from Bell's Ravine to the crater rim near the Fishing Rock road junction and was common in the Tui Lake/Dry Crater area and on the southern side of Blue Lake. All plants were destroyed (Fastier 1994).

More mature plants and saplings were killed on the southern side of Blue Lake in early 1995 (Uren 1995a) and only occasional plants were noted and removed from the northern side of Raoul.

5.5.2 *Ecology*

Purple guava is a small tree, reaching 6 m, in the myrtle family (Myrtaceae). The leaves are small (c. 5 x 3 cm) and glossy and the trunk is smooth with pale brown to reddish bark. The easiest way to find purple guava in the forest is to look for the trunk, as none of the native species look like this. Trees flower from June to March and fruit from late summer into autumn. The fruits are usually purple (occasionally yellow) and c. 2 cm diameter (Figure 10 and 11). The numerous small seeds are dispersed by birds which eat the fruit. Probably rats also eat the fruit but destroy most of the seeds. Because purple guava seeds are bird dispersed the pattern of spread is not predictable and it could establish in remote parts of the Island. Longevity of purple guava seeds in the soil is not known but may be several years as the seed coat is very hard. Cut stumps will regenerate vigorously from basal buds (Sykes 1990).

This guava is another light-demanding species and is most commonly found near the forest edge, e.g., the edge of Blue Lake, in the vicinity of the Orchard on the Northern Terraces, or in light gaps in the forest, e.g., in the crater.

5.5.3 *Control methods*

From 1973-75 trials using Tordon 2G and diesel painted on cut or ring-barked stems were not effective as treated plants recovered by suckering. Escort was trialled for its effectiveness in killing purple guava (Crawley 1990). This species was sparse in 1991-92, and treated by cutting, peeling back the bark and spraying with Escort (Clark 1992).

Any plants located should be hand-pulled, if possible. Pulled up plants should be broken and hung up to desiccate. If the plant is too large the stem should be frilled and Escort or Ammate applied to the cambial region.

Figure 10 Purple guava with a flower and young fruit, 1944 (Photo: J.H. Sorensen).

5.5.4 *Future work*

Plots of known occurrence of purple guava should be checked annually for seedlings, and all areas of forest should be scanned for the distinctive trunks of larger individuals. Because this species can be bird dispersed all relatively open areas of forest are susceptible to invasion.

5.6 *Psidium guajava* – YELLOW GUAVA

5.6.1 History

Yellow guava was introduced to Raoul as a fruit tree by the settlers of last century (Smith 1887, Cheeseman unpub.). It was not recorded as a naturalised plant until 1964 (Sykes 1965) when it was noted forming large suckering thickets on the northern side of the Island, in the crater and at Denham Bay. As with purple guava, yellow guava has not been noted in large numbers on Raoul Island. However, because this species is invasive in other Pacific Islands, eradication is desirable before the species does become a problem. Eradication commenced in 1972 and by 1980 there were still plants present above the Woolshed (Sykes 1980). In 1984 further plants were seen including one near Blue Lake which had been cut and poisoned but had resprouted (Sykes 1984). Gardner (1988) killed 92 yellow guava, mostly west of Bell's Ravine, and two from Denham Bay. Four plants growing between Denham Bay track and Bell's Ravine were killed in October 1990 (Crawley 1990). Sykes (1990) noted the persistence of this species in sites from which it had been known for many years, e.g., Denham Bay, Fishing Rock turn-off, by the road near the Woolshed, and near Blue Lake. In 1994, yellow guava was found in, and removed from, only two locations: the Orchard and the western shoreline of Blue Lake (Fastier 1994). One mature, fruiting plant has been removed from near Blue Lake since then (Uren 1995a).

5.6.2 Ecology

Yellow guava is a small tree, growing to c. 3 m, in the myrtle family (Myrtaceae). The leaves are large (up to 14 x 7 cm) and have strong venation. Young leaves are densely hairy. The bark is smooth, like that of purple guava. Flowering is from July to March and fruiting from summer to autumn. The fruit are up to 4 cm diameter and yellow-skinned and the many hard seeds are dispersed by birds. Rats will also eat the fruit but will destroy many of the seeds. This species persists by sprouting from basal and lateral buds when the main stem is cut, and spreads by suckering (Sykes 1990).

Figure 11 Unripe fruit on purple guava, 1944 (Photo: J.H. Sorensen).

Dispersal of yellow guava cannot be predicted because it is bird dispersed. It has had a relatively wide distribution in the past: Denham Bay, the Northern Terraces, Low Flat and the crater. However, like purple guava, this species is light demanding so will be found in light gaps or at the forest edge.

5.6.3 *Control methods*

From 1973-75 trials using Tordon 2G and diesel painted on cut or ring-barked stems were not effective as treated plants recovered by suckering. Sykes (1980) recommended the use of a tractor to pull out plants on the slopes above the Woolshed, given their resistance to sprays and their ability to resprout once cut.

Any plants located should be hand-pulled, if possible. Pulled up plants should be broken and hung up to desiccate. If the plant is too large the stem(s) should be frilled and Escort or Ammate applied to the cambial region.

5.6.4 *Future work*

Plots of known occurrence of yellow guava should be checked annually and all areas of forest should be scanned for the distinctive trunks of larger individuals. Because this species can be bird dispersed all relatively open areas of forest are susceptible to invasion.

5.7 *Olea europaea subsp. cuspidata* – AFRICAN OLIVE

Previously *Olea europaea* subsp. *africana*

5.7.1 *History*

This species would have been introduced to Raoul for its fruit, but possibly only this century since it was not noted by Cheeseman (1888, unpub.) or Oliver (1910). There is a note in Oliver's notebook (c. 1908) which is attributable to S. Percy Smith: "Olives also would flourish there". It is possible, then, that members of the Kermadec Islands Fruit and Produce Association syndicate took olive plants to the Island, following Smith's suggestion. Sykes (1977a) records African olive as being abundantly naturalised in 1967 on the Terraces, from the Meteorological Station to around Bell's Ravine. African olive was particularly concentrated in the Orchard covering practically the entire bush fringe from the implement shed back toward the main orange grove and past the Kalona Plot. It was mostly in semi-grassed areas but there were many trees on the bush ridges leading up to the cliff base (Anon. 1982a).

Eradication of African olive commenced in 1973 when a number of the larger trees (one 12 x 12 m) were cut down (Anon. 1982a). Considerable effort was put into locating and killing this species, including assistance from some Meteorological Service staff (Trotter 1976), and by 1980 it was mainly confined to a small area of the Orchard near the Kalona Plot and to the slopes above the Woolshed (Sykes 1980) although, during 1980, 700 trees were removed from the Orchard (Selby 1980). The species was still present in low numbers at the same sites in 1984, although some plants were nearly mature (Sykes 1984). Bracefield (1987) killed 38 olives: three were large trees and most were from the Orchard. Gardner (1988) killed 106, mainly from the Orchard. In 1990, Sykes observed one adult and one seedling in the Orchard close by the Hostel. Clapham (1991 a) killed 86 African olive seedlings, mainly <1 m tall. Although,

dispersed along the northern side of the Island from near the Woolshed to the Orchard area near the Hostel, and is occasional on the shore of Blue Lake and lower slopes of Mt Campbell. It has been found up near the transition zone of dry and wet forest (Uren 1995b). Thus, it has expanded its range since 1967.

5.7.2 Ecology

African olive is a tree, up to c.12 m tall, in the olive family (Oleaceae). The leaves are green above and slightly grey below. Abundant small flowers are produced from July to March and the fruits are present from summer to autumn. Fruits are small (c. 8 mm diameter) and black, when ripe, and are eaten by birds. Rats may also eat and destroy seeds. Because this species is bird dispersed, it is likely to appear in locations remote from the original trees. However, like most other category A species it is also light demanding so will be found in light gaps or at the forest edge.This species suckers freely from cut stumps.

5.7.3 Control methods

From 1973-75 mature trees were cut and poisoned with Tordon 2G or 520 and diesel. This method was reasonably successful, although Dale (1979) noted regrowth and resistance to sprays used. Cutting stems without herbicide application resulted in regeneration of stumps by suckering. Seedlings of African olive were hand pulled. Sykes (1980) records the resistance of this species to herbicides and notes its ability to resprout from cut stumps. Selby (1980) noted that 12 different poisons were tried on this species but, apart from Tordon 520, none seemed to work. He wrenched all trees and burnt them. In this way, over 700 trees were killed in one year in the Orchard alone. Crawley (1990) noted that Escort was trialled for its effectiveness at killing African olive.

Any plants located should be hand-pulled, if possible. Pulled up plants should be broken and hung up to desiccate. If the plant is too large the stem(s) should be frilled and Escort or Ammate applied to the cambial region.

5.7.4 Future work

Plots of known occurrence of African olive should be checked annually and all areas of forest should be scanned for this species. Because this species can be bird dispersed all relatively open areas of forest are susceptible to invasion. Aerial reconnaissance by helicopter should also be used to check the distribution of African olive. The height that mature trees can reach plus the form of the tree canopy may enable mature specimens to be seen from the air.

5.8 *Cortaderia selloana* – PAMPAS GRASS

5.8.1 History

Pampas grass is one of the most recent plant introductions to Raoul Island and was first recorded on a retaining wall built near the flying fox at Fishing Rock in 1976. It appears that the final step of building an effective retaining wall was to sow some plant cover and pampas grass, a species not present on Raoul, was used. The pampas, and its assumed method of introduction was recorded by Sykes (1984), who removed the plants promptly. One of the plants had flowered earlier in the year. In 1990, Sykes inspected the retaining wall and found five or six plants, one of which had flowered. All of these plants were destroyed. Three plants were removed from the site in 1991 (Clapham 1991a). During my visit in 1993 a single juvenile plant which was growing on the retaining wall was pulled out.

The ease with which this plant was introduced to the Island illustrates the need for vigilance over movement of materials to Raoul.

5.8.2 Ecology

Pampas grass is a tall, tussock-forming species in the grass family (Poaceae) and the leaves have sharp, cutting edges. The flowers are borne in dense plumes on stalks up to 2 m tall and later develop into numerous wind-dispersed seeds. Pampas grass is a coloniser of open ground, and on islands such as Little Barrier has colonised open coastal sites. On Raoul, there are many open coastal faces and ridges which could be invaded by pampas. Since pampas grows taller and more densely than the species which currently colonise such sites it would be a very strong competitor and would dominate the sites, effectively halting forest regeneration.

5.8.3 Control methods

Hand-pull any seedlings which appear.

5.8.4 Future work

The last plant at the site was removed in 1993. The retaining wall and environs of the top winch shed at Fishing Rock should be checked annually until at least 2003 to ensure that any further plants which might germinate from seed stored in the soil are removed. Seed longevity of pampas is not known.

Figure 12 View west along Low Flat beach towards the Norfolk pines, 1944. At the extreme left on the skyline Norfolk pines naturalised in the forest are visible (Photo: J.H. Sorensen).

5.9 *Araucaria heterophylla* – NORFOLK PINE

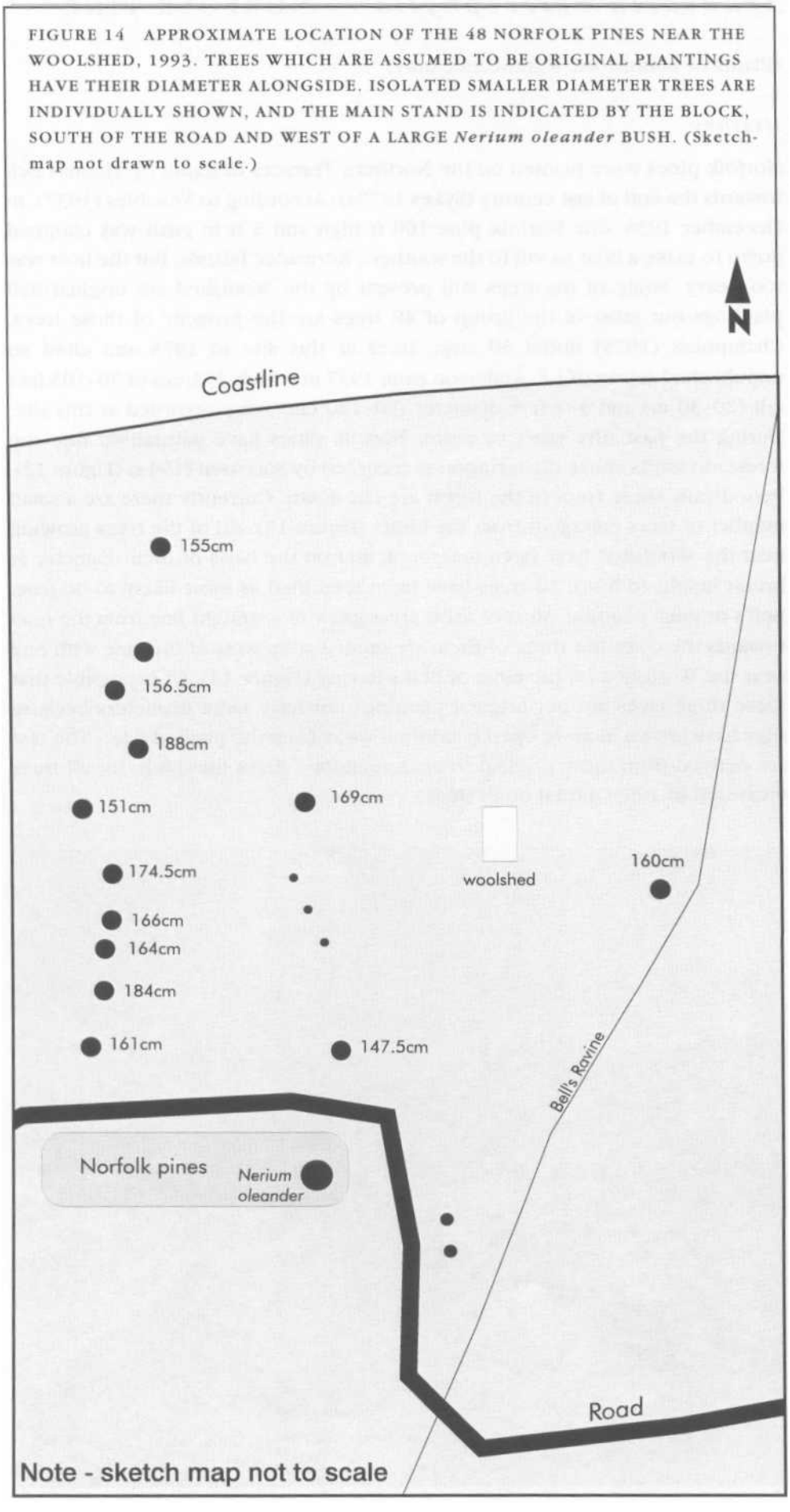
(Plants of nonhistoric significance only)

5.9.1 History

Norfolk pines were planted on the Northern Terraces of Raoul by Thomas Bell towards the end of last century (Sykes 1977a). According to Venables (1937), in December 1936, one Norfolk pine 100 ft high and 5 ft in girth was chopped down to make a boat to sail to the southern Kermadec Islands, but the boat was too heavy. Some of the trees still present by the Woolshed are original Bell plantings but most of the group of 48 trees are the progeny of those trees. Champness (1975) noted 50 large trees at this site in 1975 and cited an unpublished report of J.E. Anderson from 1937 in which 23 trees of 70-103 feet tall (20-30 m) and 3-4 feet diameter (90-120 cm) were recorded at this site. During the past fifty years or more, Norfolk pines have naturalised into the forest, on bluffs above the terraces, as recorded by Sorensen (1944) (Figure 12). Periodically these trees in the forest are cut down. Currently there are a small number of trees emergent from the bluffs (Figure 13). All of the trees growing near the Woolshed have been measured, and on the basis of their diameter at breast height (d.b.h.), 12 trees have been identified as most likely to be from Bell's original planting. Most of these trees grow in a straight line from the road towards the coast but three of them are immediately west of this line with one near the Woolshed on the edge of Bell's Ravine (Figure 14). (It is possible that these three trees are not original plantings but have large diameters because they have grown in more open conditions away from the planted line.) The rest are derived from these original trees. Appendix 4 gives the d.b.h. for all trees measured in 1993; a total of 48 trees.

Figure 13 The same view in November 1994 showing the main group of Norfolk pines (see map in Figure 14) and outliers naturalised in the forest further inland.

FIGURE 14 APPROXIMATE LOCATION OF THE 48 NORFOLK PINES NEAR THE WOOLSHED, 1993. TREES WHICH ARE ASSUMED TO BE ORIGINAL PLANTINGS HAVE THEIR DIAMETER ALONGSIDE. ISOLATED SMALLER DIAMETER TREES ARE INDIVIDUALLY SHOWN, AND THE MAIN STAND IS INDICATED BY THE BLOCK, SOUTH OF THE ROAD AND WEST OF A LARGE *Nerium oleander* BUSH. (Sketch-map not drawn to scale.)



A group of 4 trees at the south end of Denham Bay was established this century. They were assumed to have been planted by the Bells (Champness 1975). A photograph of the south end of Denham Bay taken by Oliver in 1908 shows no trace of Norfolk pines (Figure 15), but by 1944, when Sorensen was on the Island, they were obvious (Figure 16). Although instructed to remove these trees in 1976, the weed team left them because of concern for their possible historic value (Trotter 1976). Today they are still a prominent feature of the landscape (Figure 17).

Since the commencement of the weed eradication programme, thousands of Norfolk pine seedlings have been pulled out. Taylor (1974) removed one 8 ft tall tree from the track to Denham Bay near the top of the ridge. In 1975, 1023 seedlings and 5 young trees were killed in Denham Bay (Champness 1975). Bracefield (1987) removed six plants from Denham Bay. Gardner (1988) killed 130 plants in Denham Bay. Six plants were removed near Bell's Ravine in October 1990 (Crawley 1990). In March 1991, 2500 seedlings were pulled out in Denham Bay (Crawley 1991b) and a further 4000 were removed the following month (Crawley 1991c).

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