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ATMOSPHERIC CORROSION RATES OVER TWO YEARS EXPOSURE AT 156 SITES IN NEW ZEALAND

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This paper reports atmospheric corrosion rates for the first two years for mild steel, galvanised steel and aluminium, for 156 sites distributed throughout New Zealand, in a programme designed for 1, 2, 5 and 10 year exposure time periods. The data show that designers should regard the proximity to the coast as the most important general factor in deciding on the protection levels against atmospheric corrosion of metals in New Zealand. Major industry installations can introduce some secondary factors that need consideration. There are special problems in the Rotorua region, for mild steel and galvanised steel, but aluminium seems able to perform satisfactorily and may be a more desirable metal for use in this environment, where atmospheric H_2S is evolved from geothermal activities. Maps indicating corrosivity rates for steel and galvanised steel are provided for the guidance of designers.

Keywords: aluminium — atmosphere — corrosion — galvanised steel — New Zealand — steel

1. Introduction

New Zealand's climate is dominated by prevailing westerly winds flowing across the land from over the Tasman Sea. These winds can carry sea salt large distances inland, and so pose potential atmospheric corrosion problems[1]. Prior to 1980, few data on atmospheric corrosivity levels in New Zealand had been published, and a set of proposed atmospheric corrosivity zones for mild steel in New Zealand[2] had to be based largely on theoretical analysis. A number of studies (eg Refs 1,3) have subsequently provided data on individual areas in the 1980s.

In 1987, BRANZ began a major project to provide a unified map of the atmospheric corrosivity of New Zealand. Three common technological metals — mild steel, galvanised steel and aluminium — were chosen for the study, to allow designers of all structures from fences to electricity transmission towers to buildings to have an assessment of the potential for atmospheric corrosivity at whatever site they were designing for. Values for atmospheric corrosion rates of unpainted panels of mild steel, galvanised steel and aluminium exposed for one year at 168 sites spread through New Zealand have been presented previously[4,5]. This paper lists those data again, and presents the data from two years exposure for 156 of these sites, and comments on the variability of values.

2. Experimental

The experimental method has previously been explained in detail[4]. In brief, mild steel, galvanised steel and aluminium panels were exposed on racks facing north, at 45 degrees to the vertical, approximately 1.8 m above the ground, at 168 sites spread throughout most of New Zealand. The coupons were cut from commercially produced sheet material bought from local suppliers, to size 150 x 100 x 3 mm (mild steel and aluminium) and 150 x 100 x 0.5 mm (galvanised steel). Composition of these materials is given in Table 1. The aluminium is nominally of grade AA 1100. The mild steel coupons were supplied grit blasted to SA3[6]. The galvanised steel coupons were cut from coil specified as Z300 coating to NZS 3441:1978[7]. Prior to exposure the coupons were degreased in acetone and weighed to ±0.01 g.

Four panels of each metal were mounted one above each other, with spaces between, in each rack. Figure 1 shows the type of rack used. The replicate panels were intended to be collected after 1, 2, 5 and 10 years exposure. Most of the sites at which racks were erected were climatological stations operated by NZ Meteorological Service. As reorganisation of state sector organisations in New Zealand has continued, some of the sites used no longer have people able to oversee the racks and collect specimens from them as required. This has resulted in 12 sites fewer in the two-year data set than in the one-year set. At some other sites, all remaining panels have now been collected and analysed and the site closed down.

The racks were put in place between March and September 1987. Coupons in racks placed before June had a protective plastic wrapping left on until removed by the site operators on, or about, 19 June 1987, which was regarded as the start date for these sites. The presence of the plastic did not affect the susceptibility to corrosion once the plastic was removed[4]. For the two-year exposure assessment, a single coupon of each metal was retrieved from each rack on or about the 9th August 1989.

The corrosion products were removed from the coupons using the methods specified in ASTM G1-81[8], sections 5.1, 5.2, 5.5 and 5.7.2, except that the antimony trioxide was omitted from the mild

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steel cleaning solution (due to difficulty in obtaining it). The coupons were then reweighed and weight losses calculated. Correction factors for losses incurred during corrosion product removal were determined and applied to the raw data.

3. Results

The results from the first two years exposure are shown in Appendix 1. The alphanumeric reference beside locations is the NZ Meteorological Service site designation, where such a site was used. The data for mild steel and galvanised steel are shown in map display in Figures 2 to 5; these are indicative only, and the precise data should be taken from the Appendix rather than the maps. Figures 6 to 8 show the comparison between the one and two-year data. Some of the data points for the area around Rotorua were not included in Figures 6 to 8, because they are so much larger than the other values for mild steel and galvanised steel.

The panels were generally uniformly corroded, although in the Rotorua region the skyward surface of galvanised steel coupons tended to be more corroded than the surface facing the ground. After cleaning, the steel samples were covered in a finely pitted surface. There was minimal difference in appearance between the backs and fronts of the aluminium panels, such as might have been characteristic of differential rates on the two faces.

Table 2 shows the results collected from those sites where more than one panel was collected after two years. These results indicate a within-site standard error of 0.12 $g/m^2/yr$ for aluminium, 1.05 $g/m^2/yr$ for galvanised steel, and 13.5 $g/m^2/yr$ for mild steel for the two-year data. These are comparable to those found in the one-year data.

4. Discussion

4.1 The absolute values for the corrosion rates.

One-year corrosion rates for steel have varied from 18 to 4800 $g.m^{-2}.yr^{-1}$ and two-year values from 9 to 5300 $g.m^{-2}.yr^{-1}$. For galvanised steel, the rates at one year were 0.7 to 141 $g.m^{-2}.yr^{-1}$, and after two years from 0.5 to 76 $g.m^{-2}.yr^{-1}$. In each case, the extreme high values are found in the geothermal region, and the extreme low values in the central South Island.

Figures 2 to 5 show clearly that the most important factor is the distance from the coast, except in the Rotorua region of the North Island, confirming the indications from an earlier study[1] in two regions that the amount of deposited sea salt is a controlling factor for atmospheric corrosion rates in New Zealand.

Though the metallurgy of a coil-coated zinc layer on steel will be slightly different from that of a zinc sheet, the surface chemistry could be expected to be similar, and the results for galvanising will provide a guide for sheet zinc.

Corrosion rates for aluminium in each period are extremely low, and it has been chosen not to present them in map form here. Different aluminium alloys seem to perform generally alike in marine environments, excepting the Al-Cu alloys (AA-2000 series) which are less durable[9]. Thus a corrosivity map would show most of New Zealand to be of low corrosivity with a band of medium corrosivity around the coast reaching perhaps up to 10 kilometres inland. With aluminium, however, microclimatic effects can have an overriding influence on corrosion performance, and so such a map would probably be less used.

The apparently off-set origin in Figure 8 is an artefact of the "blank correction" methods used. Aluminium forms a thin adherent layer of corrosion product which is difficult to remove. As the weight differences involved are very small on these panels, small weighing errors or small amounts of adherent corrosion product remaining can give an apparent weight gain rather than the weight loss expected.

There are unexplained anomalies in the zinc data for the Thorndon site (Wellington region, North Island), where the total weight loss of the panels seems little different at the end of the second year from at the end of the first. The increased rates in the vicinity of the Kinleith paper mill (Taupo region, North Island) for steel and galvanised steel has again shown up, and otherwise the importance of proximity to the coast (especially west and south coasts) has shown through as an extremely important factor.

4.2 Comparison between one and two-year data.

Conventional theory[10] has it that zinc corrosion rates should be reasonably linear with time, while steel corrosion rates should decrease in apparent rate, as the corrosion product accumulation on the surface in second and subsequent years has some impact on the kinetics of the corrosion.

Experience shows that these theoretical expectations are not always achieved in practice[11], and Figures 6 to 8 show this phenomenon in this study. The distribution of values for the ratio of one to two year data for steel and zinc resemble those found at a wide range of US sites away from the immediate seashore[11], for steel at a large number of sites around Melbourne[12], and for mild steel, galvanised steel and aluminium at a set of six sites in South Taranaki[3].

Some of the apparent variability in measured corrosion rates, which show in these measurements as points lying off the linear band, will emerge from errors in the measurements. But this cannot explain results such as those found for the Thorndon (Wellington region, North Island) site for galvanised steel, or Lake Grassmere (Marlborough region, South Island) for steel, where corrosion rates several times the likely error from this source occur, but there has been apparently no further corrosion in the second year. Some of the variations may be attributable to drier/wetter weather during the second year, with more/less onshore wind. With the decrease in open availability of this type of meteorological data in New Zealand due to commercialisation, and the impractical expense of buying such data for all the sites at which corrosion data has been collected, these hypotheses cannot be tested.

4.3 Geothermal zone

The data for the Rotorua region of the North Island emphasise again the highly variable nature of corrosion adjacent to fumaroles, the relatively higher corrosion rates of steel and galvanised steel in this region compared with other inland areas — even away from the sites which gave extreme values — and the relative unaffectedness of aluminium. Practical experience bears out this measurement, with aluminium components seeming markedly more durable than galvanised steel in this region. It is a predictable effect on theoretical grounds. The thin protective oxide film on aluminium is moderately resistant to attack by acids of the strength which would occur in the atmosphere (but disrupted by the presence of chloride), while the convertible oxide film that forms on zinc is readily soluble in the types of acid that can occur.

The distribution of measurements reported here can give little selective guidance to designers in this Rotorua region, except a general warning to be wary. There is clearly scope for a more detailed study in this area which uses a grid pattern and relates the corrosivity found to the natural features if possible, in the fashion that greater Melbourne has been assessed[12]. But to be useful, the grid may have to be on no more than one kilometre centres — and possibly even less.

In the earlier theoretical assessment of hazards for atmospheric corrosion of steel[2], this zone of "special conditions" was said to be bounded by Te Puke, Kawerau, Waiouru and Ohakune. The study has so far been rather inconclusive for the area south of Taupo; Waiouru is showing a higher value for steel corrosion, but Turangi and Ohakune are not.

5. Conclusions

One and two years' exposure of atmospheric corrosion test panels has been carried out, and the analysed data show comparative rates for over 150 sites in New Zealand. The data show that designers should regard the proximity to the coast as the most important general factor in deciding on the protection levels against atmospheric corrosion to be used for metallic building materials. Major industry installations — with Kinleith as an example — can introduce some secondary factors that need consideration. There are special problems for mild steel and galvanised steel in the Rotorua region, where atmospheric H_2S is evolved from geothermal activity. But aluminium seems able to perform satisfactorily and may be a more desirable metal for use in this environment.

6. Acknowledgements

Nigel Kell and Leigh de Vre cleaned some of the panels. Sarah Harper assisted with statistical analysis of the results. Surveys such as this are impossible without the assistance of the site owners, and we thank them sincerely, and also thank Mr John Falconer of NZ Meteorological Service for his assistance in the original negotiations for use of sites.

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TABLE 1: Composition of coupons (weight percent).

Steel	C	N	Al	Si	P	S	Ti	V	
	0.18	0.003	0.007	0.04	0.027	0.014	0.005	0.002	
	Cr	Mn	Ni	Cu	Mo	Sn	Nb	Fe	
	0.03	0.69	0.02	0.03	<0.001	<0.001	<0.001	balance	
Galvanised steel	Mg	Al	Cu	Sn	Pb	Zn			
(in zinc coating)	<0.01	0.32	<0.01	<0.01	0.10	balance			
Aluminium	Mg	Si	Ti	Cr	Mn	Fe	Cu	Zn	Al
	0.13	0.22	<0.1	<0.005	0.015	0.53	0.035	0.003	balance

TABLE 2: Corrosion rates ($g.m^{-2}.yr^{-1}$) found at sites with more than one panel collected at the end of two years' exposure

	Mild steel	Galvanised steel	Aluminium
Arapuni	72, 77	1.8, 1.7	0.3, 0.5
Judgeford	101, 120 ,97, 104	3.2, 4.3, 3.8, 3.8	0.5, 0.6, 0.4, 0.5
Glenbrook	108, 110	2.3, 2.4	0.7, 0.8
Cambridge	91, 90, 107	1.3, 4.9, 2.1	0.4, 0.1, 0.1
Wharerata	85, 77, 81	–	–
Dunedin Aero	65, 122	–	–
Wairakei	103, 101	–	–

– Panels not collected

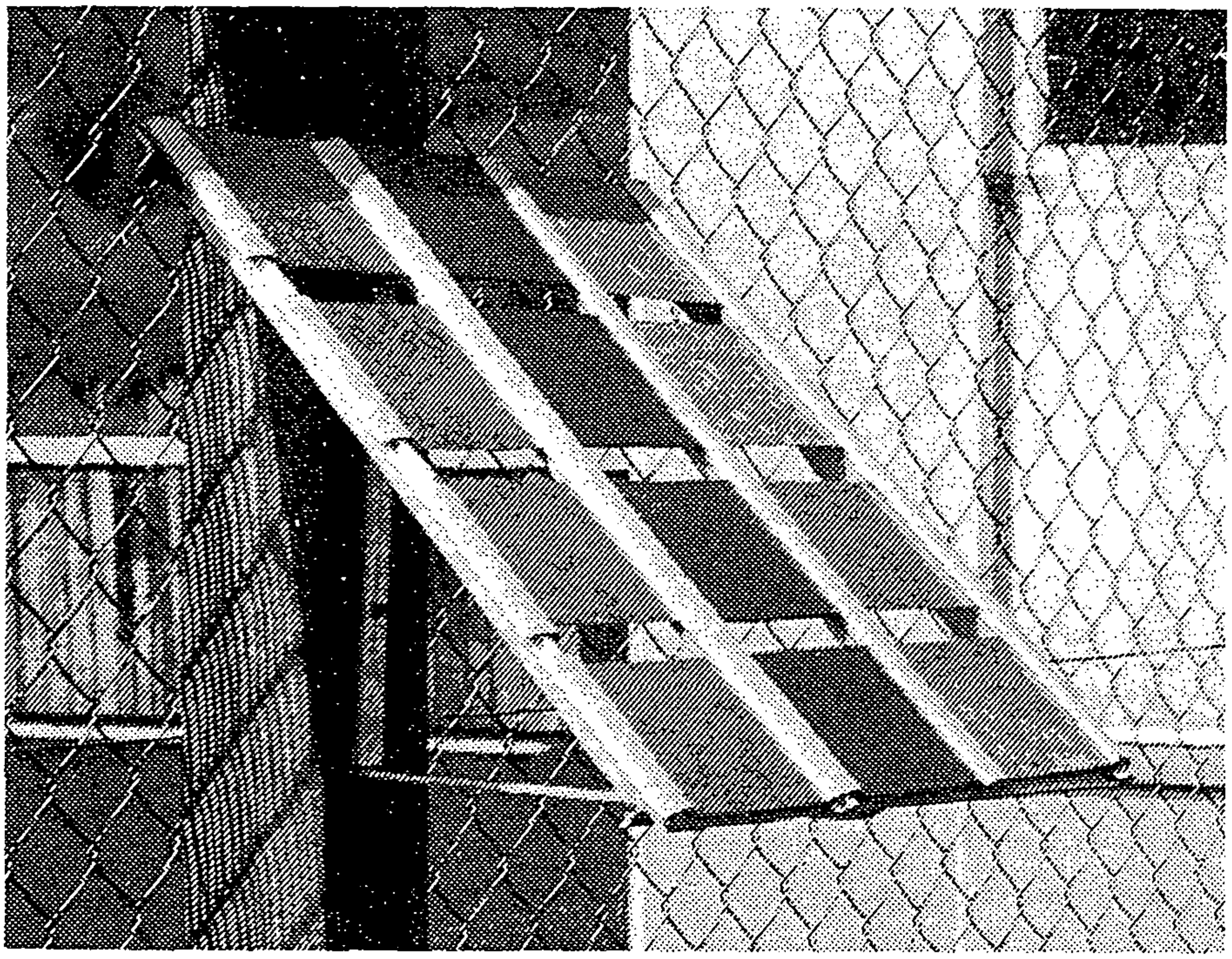

FIGURE 1: Typical rack carrying panels.

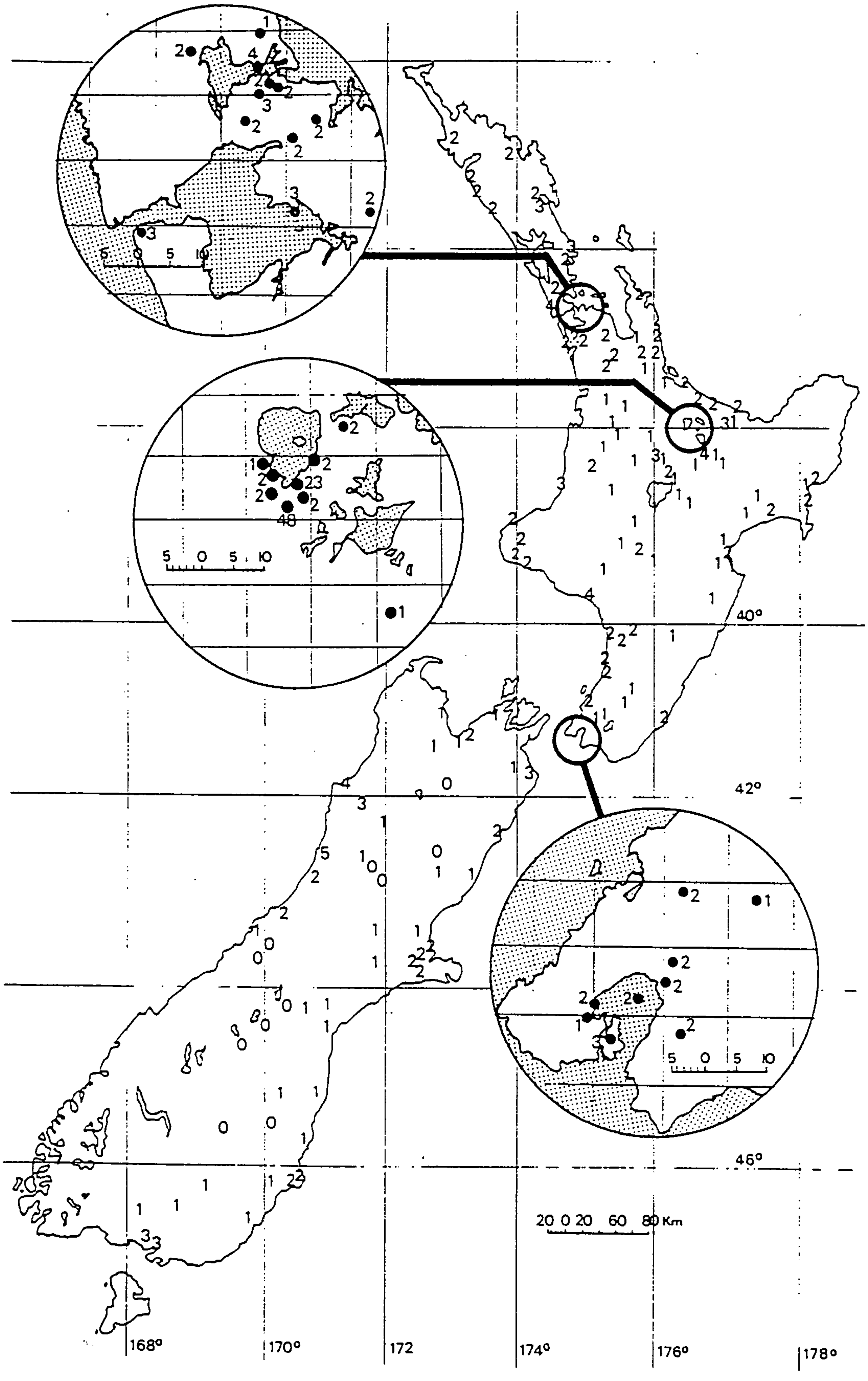

Figure 2: Mapped distribution of steel corrosion rates over one years exposure. Units are rounded, and 1 = 100 $g.m^{-2}.yr^{-1}$

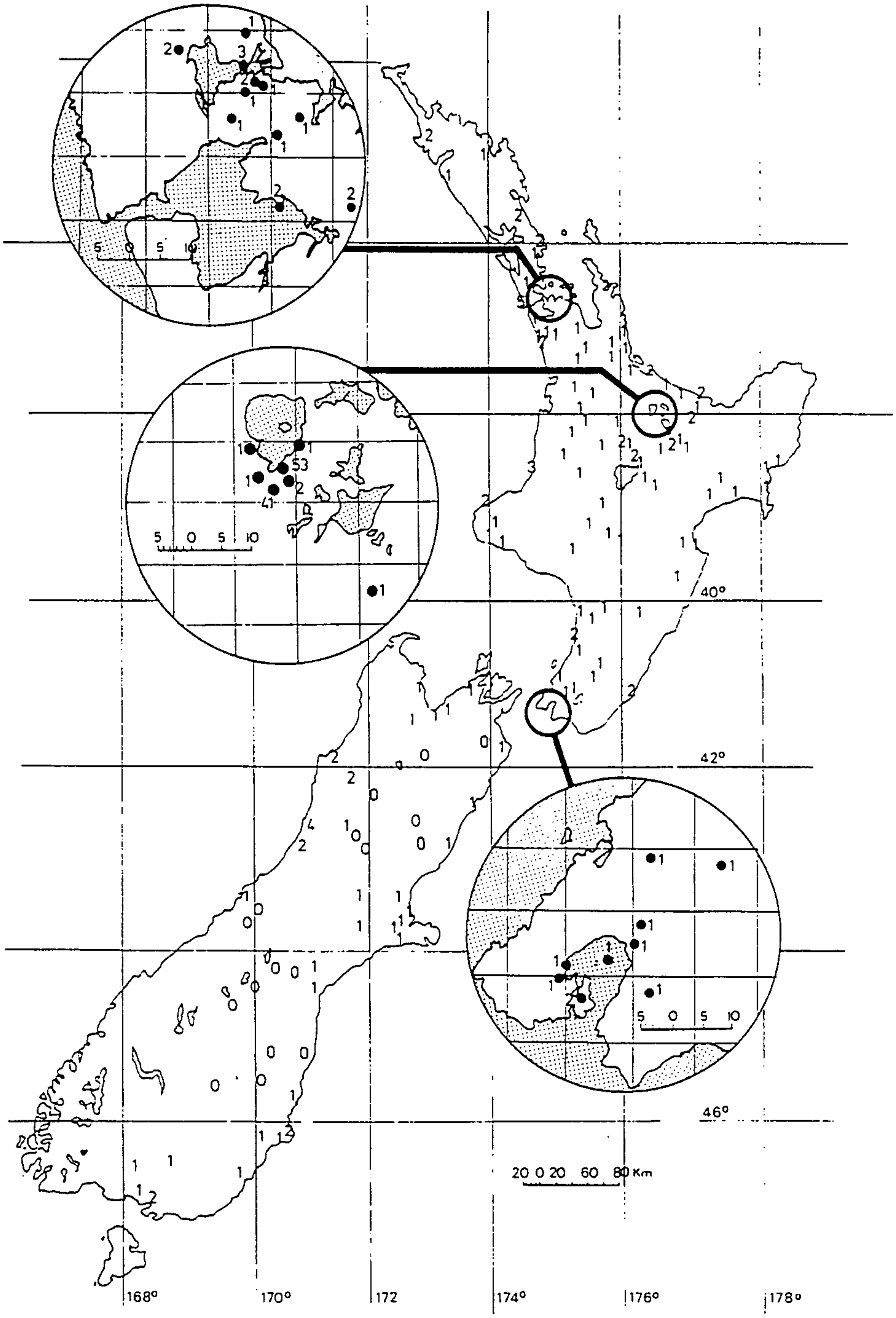

Figure 3: Mapped distribution of steel corrosion rates over two years exposure. Units are rounded, and 1 = 100 $g.m^{-2}.yr^{-1}$

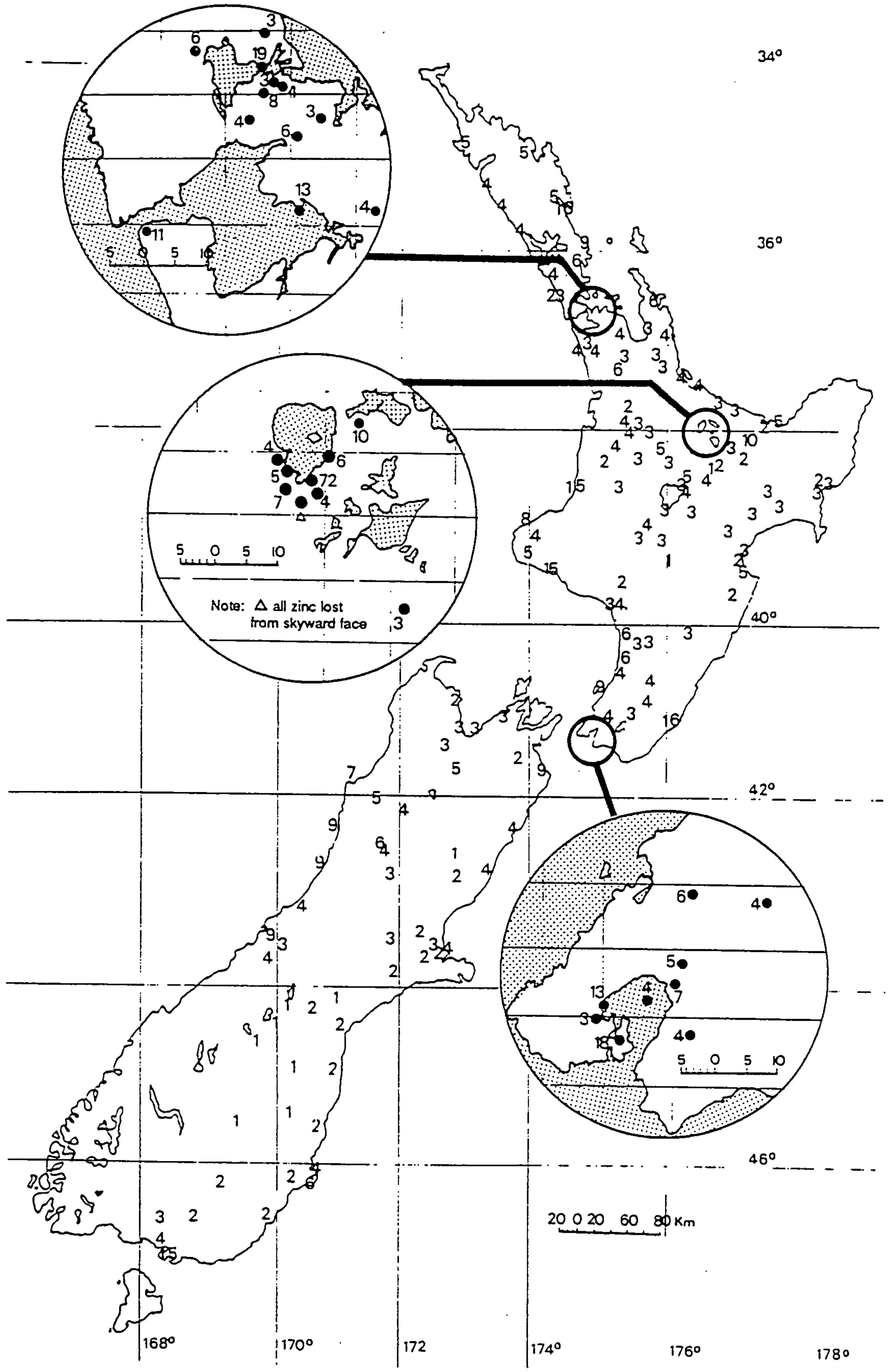

Figure 4: Mapped distribution of zinc corrosion rates over one years exposure.
Units are rounded, to nearest $g.m^{-2}.yr^{1}$

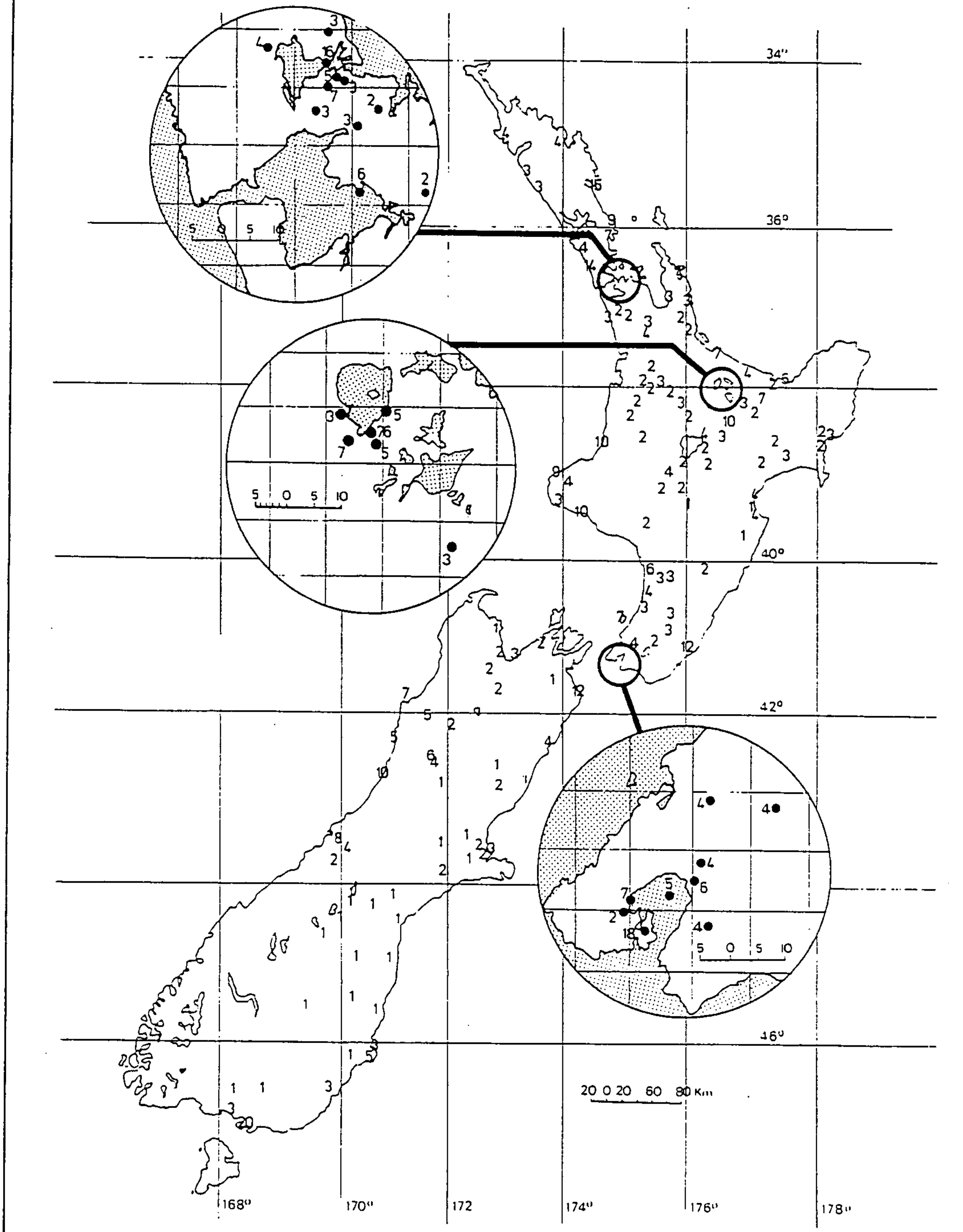

Figure 5: Mapped distribution of zinc corrosion rates over two years exposure. Units are rounded, to nearest g.m⁻².yr⁻¹

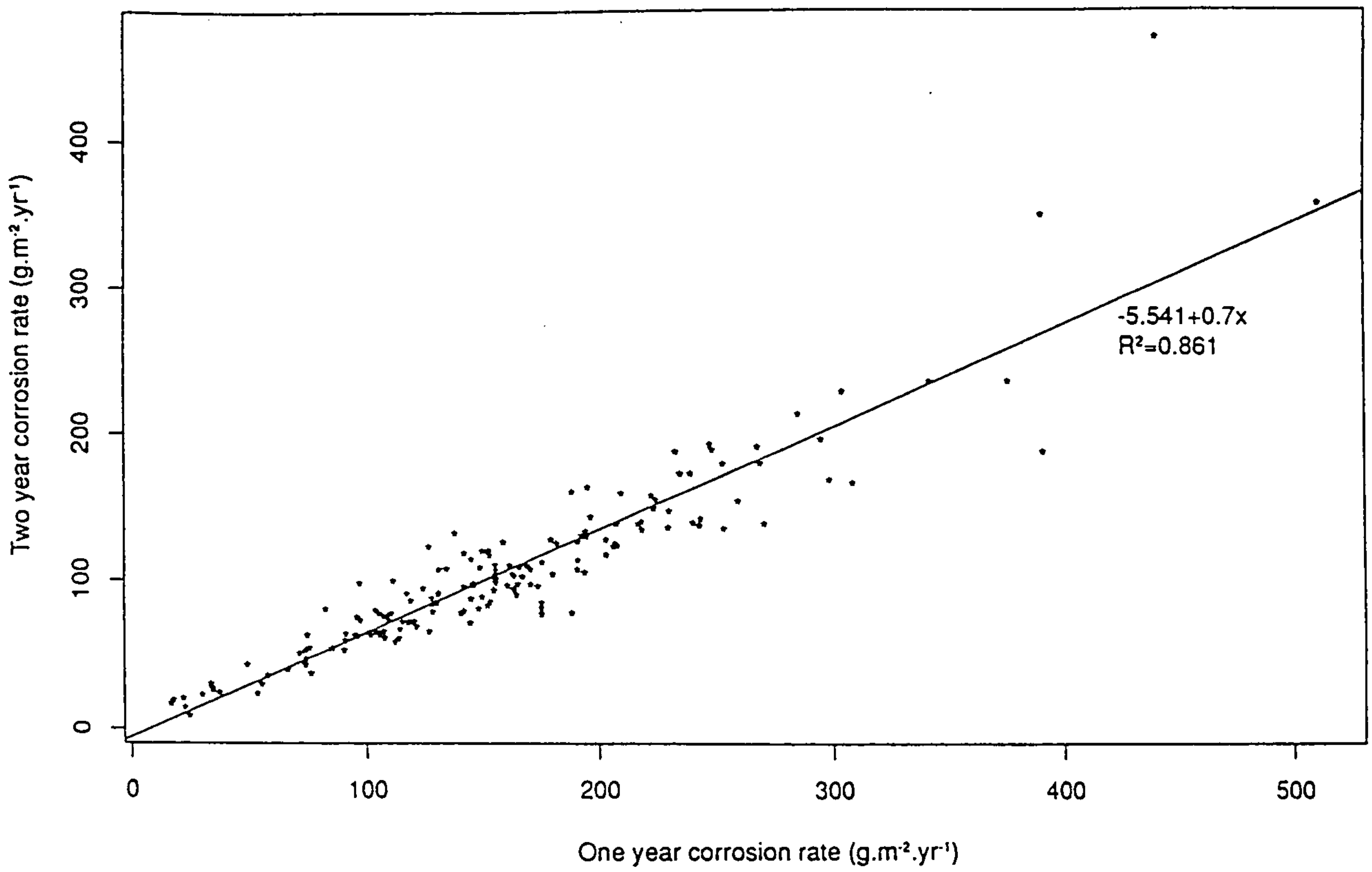

FIGURE 6: Comparison of mild steel corrosion rates over one and two years.

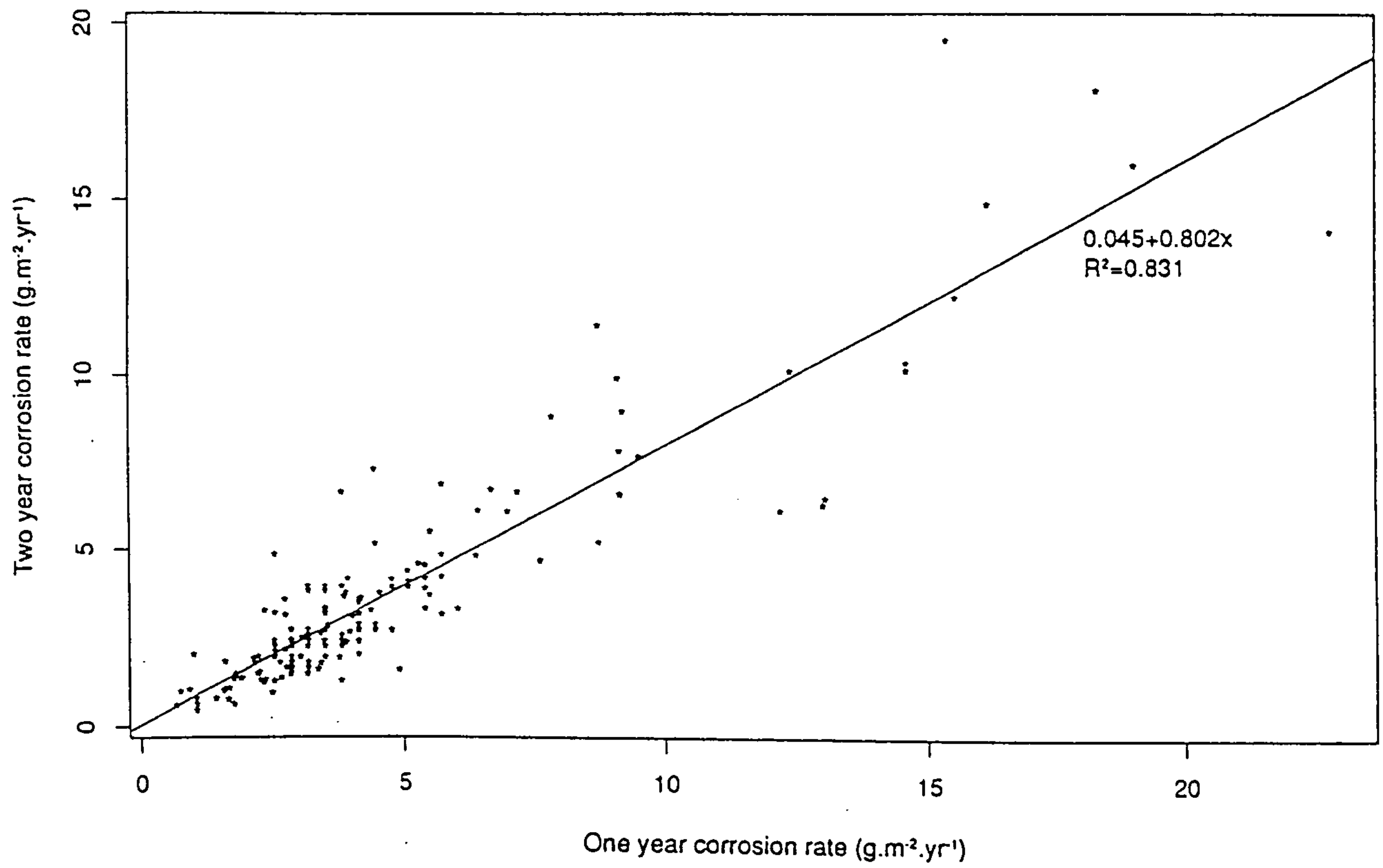

FIGURE 7: Comparison of galvanised steel (and thus zinc) corrosion rates over one and two years.

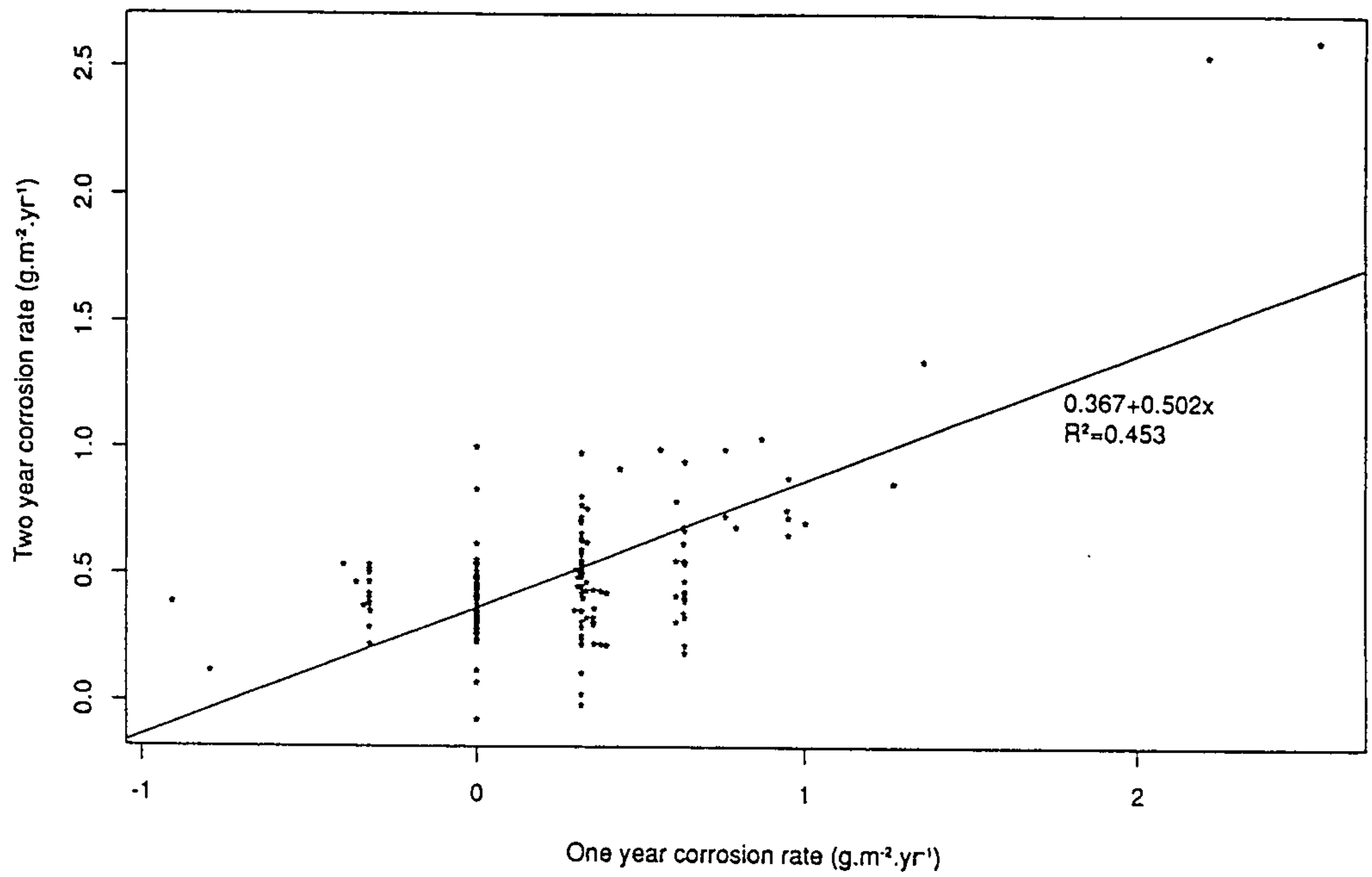

FIGURE 8: Comparison of aluminium corrosion rates over one and two years.

Appendix 1: Measured corrosion rates ($gm^{-2}.yr^{-1}$)

Note : - Implies missing data

NORTH ISLAND

SITE (LATITUDE, LONGITUDE)	YEAR ONE STEEL	YEAR ONE ZINC	YEAR ONE ALUMINIUM	YEAR TWO STEEL	YEAR TWO ZINC	YEAR TWO ALUMINIUM
NORTHLAND						
Kaitaia A53125 (35.06, 173.15)	188	5.1	0.3	160	4.0	0.4
Kerikeri Aero A53293 (35.16, 173.55)	203	4.8	0.6	128	4.0	0.3
Waiotemarama A53541 (35.31, 173.25)	179	4.4	-0.3	128	2.9	0.4
Waipoua Forest A53651 (35.39, 173.33)	158	4.1	0.0	-	2.8	0.4
Dargaville A53982 (35.37, 173.50)	212	3.6	0.0			
Whangarei Aero A54733 (35.36.174.22)	234	5.1	0.0			
Marsden Point A54842 (35.53, 174.28)	285	16.2	0.3	213	14.9	0.7
Leigh (36.18, 174.48)	304	9.2	1.4	228	9.0	1.4
Warkworth A64463 (36.26, 174.40)	191	5.7	0.3	126	7.0	0.2
Woodhill Forest A64741 (36.45, 174.26)	191	3.5	0.3	113	3.9	0.6
Muriwai (36.50, 174.27)	440	22.8	1.0	469	14.1	0.7
AUCKLAND						
Whenuapai A64761 (36.47, 174.38)	248	5.7	0.3	189	4.3	0.9
Takapuna (36.48, 174.45)	142	3.2	0.3	118	2.6	0.5
Albert Park A64878 (36.51, 174.46)	152	3.8	0.3	120	6.7	0.6
Auckland City A64878 (36.51, 174.46)	259	7.6	1.0	154	4.8	0.8
Parnell (36.52, 174.48)	165	3.2	-0.3	109	2.6	0.6
Auckland Harbour Bridge (36.51, 174.46)	390	19.0	2.2	349	16.0	2.6
Owairaka A64971 (36.54, 174.44)	152	4.1	0.6	119	3.2	0.5
Penrose (36.56, 174.51)	229	6.0	0.0	136	3.4	0.4
Ellerslie (36.55, 174.51)	190	3.2	0.0	102	2.3	0.4
Auckland Aero C74082 (37.01, 174.48)	298	13.0	0.3	169	6.3	0.8
Ardmore C74091 (37.02,174.58)	209	3.5	0.3	159	2.3	0.6
South Head (37.04, 174.33)	327	11.4	1.4			
WAIKATO						
Pukekohe C74282 (37.12, 174.52)	192	4.1	0.0	130	2.4	0.5
Glenbrook (37.13, 174.45)	155	3.3	0.8	109	2.4	0.8
Maioro Forest C74371 (37.21, 174.43)	181	3.8	0.0	125	2.6	0.5
Hunua C75003 (37.04, 175.04)	180	4.1	0.0	104	2.9	0.3
Maramarua Forest C75321 (37.18, 175.15)	150	2.5	-0.3	89	3.2	0.5
Te Kauwhata C75412 (37.25, 175.08)	217	5.7	0.6	138	4.3	0.6
Thames B75152 (37.08, 175.32)	136	3.1	0.0			
Paeroa B75361 (37.23, 175.40)	160	3.2	0.3	96	1.7	0.6
Te Aroha B75571 (37.33, 175.43)	115	2.9	0.3	71	2.3	0.7
Ruakura C75731 (37.47, 175.19)	130	1.6	0.6	84	1.8	0.3
Hamilton Aero C75832 (37.52, 175.20)	142	3.5	0.6	95	2.0	0.7
Cambridge C75953 (37.55, 175.30)	131	2.5	0.3	96	2.8	0.2
TAUPO						
Mohakatino C84761 (38.43, 174.37)	267	14.6	0.3	191	10.4	0.9
Arapuni C85061 (38.04, 175.39)	104	2.9	0.3	75	1.8	0.4
Waikeria C85132 (38.05, 175.23)	128	3.8	0.3	83	2.4	0.6
Te Kuiti C85314 (38.20, 175.09)	124	3.8	0.3	107	2.4	0.6
Wairere C85502 (38.32, 175.00)	163	2.2	0.3	94	2.0	0.6
Pureora Forest C85551 (38.31, 175.33)	107	3.2	0.6	75	-	0.6
Taumarunui C85821 (38.52, 175.16)	105	2.9	-0.3	77	2.4	0.5
Kinleith B85285 (38.17, 175.53)	308	5.4	1.3	167	3.4	0.9
Atiamuri B86403 (38.24, 176.01)	74	2.9	0.3	47	1.8	0.6
Taupo B86602 (38.41, 176.04)	120	2.9	0.6	72	2.4	0.4
Wairakei B86611 (38.38, 176.06)	155	4.8	0.0	105	4.2	0.5
Taupo Aero B86702 (38.45, 176.05)	104	4.1	0.0	79	2.1	0.5
Waimihia Forest B86821 (38.50, 176.16)	91	3.2	0.0	64	2.4	0.5
Turangi C95085 (39.00, 175.48)	107	2.5	0.3	65	2.3	0.3
Chateau, Mt Ruapehu C95152 (39.11, 175.32)	96	3.5	0.0	62	4.0	0.4
TARANAKI						
New Plymouth Aero C94011 (39.01, 174.11)	247	7.8	0.6	193	8.9	1.1
Stratford E94333 (39.20, 174.18)	188	3.8	0.3	78	3.7	0.4
Kapuni E94413 (39.28, 174.10)	230	4.8	0.6	147	2.8	0.5
Patea E94743 (39.45, 174.28)	218	14.6	1.0	140	10.2	1.0
Ohakune E95445 (39.24, 175.25)	85	3.4	0.0	54	1.6	0.4
Waiouru E95465 (39.28, 175.41)	155	2.7	0.0	106	2.2	0.3
Ahu Ahu E95614 (39.41, 175.06)	112	2.1	0.0	58	1.8	0.5
Taihape E95683 (39.41, 175.48)	71	0.9	0.0	51	1.0	0.4
Wanganui Aero E95903 (39.58, 175.01)	352	33.6	1.1			
Paraparaumu Aero E04991 (40.54, 174.59)	240	9.1	0.6	139	6.7	0.6
Flockhouse E05221 (40.14,15116)	208	5.5	0.3	123	5.6	0.5
Kairanga E05343 (40.20, 175.28)	203	2.7	0.6	117	3.2	0.6
Palmerston North Aero E05361 (40.20, 175.37)	168	3.0	0.6	110	2.5	0.5
Waitarere Forest E05521 (40.33, 175.12)	224	5.5	0.6	154	3.8	0.9
Levin E05622 (40.39, 175.16)	194	4.0	0.6	105	2.7	0.4

	YEAR ONE			YEAR TWO		
	STEEL	ZINC	ALUMINIUM	STEEL	ZINC	ALUMINIUM
BAY OF PLENTY						
Whangapoua Forest B65761 (36.46, 175.36)	158	5.7	0.0	126	4.3	0.4
Tairua Forest B75182 (37.10, 175.51)	170	3.5	0.6	107	3.4	0.5
Waihi B75381 (37.23, 175.51)	163	4.4	0.0	93	2.8	0.7
Katikati B75592 (37.35, 175.58)	146	3.8	0.3	97	-	0.7
Tauranga aero B76621 (37.40, 176.12)	195	4.4	0.3	163	7.4	0.8
Te Puke B76835 (37.49, 176.19)	154	2.8	0.0	93	2.8	0.5
Rotoehu Forest B76951 (37.54, 176.31)	155	3.2	0.3	98	4.0	0.8
Edgecumbe B76984 (37.55, 176.55)	146	2.2	-0.6			
Whakatane Aero B76994 (37.55, 176.55)	196	5.1	0.3	143	4.5	0.6
Kawerau B86071 (38.05, 176.43)	294	9.5	0.6	196	7.7	0.8
Kaingaroa Forest B86451 (38.24, 176.34)	109	2.5	0.3	76	2.4	0.3
Murapara B86471 (38.27, 176.42)	96	1.8	0.3	75	1.5	0.6
Ohaaki D.S.I.R (38.30, 176.20)	391	12.4	0.0	188	10.1	0.0
Ohaaki Power Station (38.31, 176.19)	109	3.5	0.3	73	3.3	0.6
HAWKES BAY						
Manutuke D87683 (38.41, 177.53)	141	2.2	0.0	78	1.5	0.3
Gisborne Aero D87692 (38.40, 177.59)	194	2.8	-0.3	133	2.5	0.4
Onepoto D87811 (38.51, 177.08)	90	2.8	0.6	59	1.5	0.4
Wharerata Forest D87881 (38.52, 177.52)	175	3.2	0.3	81	1.5	-
Esk Forest D95272 (39.15, 176.42)	86	2.5	0.3			
Napier Aero D96481 (39.28, 176.52)	153	3.2	0.6	117	3.9	0.6
Havelock North D96689 (39.40, 176.53)	101	5.4	0.3	65	4.0	0.7
Taradale (39.35, 176.53)	82	1.6	0.0	80	1.0	0.6
Mohaka Forest D97004 (39.04, 177.02)	114	2.5	0.0	61	2.0	0.4
Frasertown D97042 (39.00, 177.24)	153	3.2	0.0	85	2.6	0.4
Waipukurau D06051 (40.00S, 176.32)	119	1.9	0.0	86	1.4	0.4
ROTORUA						
Tikitere B86034 (38.04, 176.21)	243	9.5	-0.3			
Rotorua Aero B86131 (38.07, 176.19)	207	5.7	0.3	138	4.9	0.7
Lynmore (38.10, 176.16)	153	4.4	0.0			
Koutu (38.10, 176.16)	117	4.4	0.0	90	2.9	0.6
Ngapuna (38.11, 176.18)	2293	71.6	0.3	5349	76.4	0.7
Springfield (38.12, 176.16)	218	6.7	0.0	134	6.8	0.6
Ohinemutu (38.11, 176.16)	222	5.4	-0.3	158	4.6	0.6
Lake Rotoatamaheke (38.12, 176.16)	4800	141.6	-	4182	-	-
Waitapu Forest B86341 (38.19, 176.25)	111	3.2	0.3	99	2.8	0.6
WAIRARAPA						
Dannevirke D06212 (40.13, 176.07)	114	3.2	-0.3	67	1.8	0.6
Castlepoint D06921 (40.54, 176.13)	232	15.5	0.3	188	12.2	1.1
Tauherenikau D15134 (41.07, 175.23)	124	2.9	-0.3	94	2.0	0.5
Mt Bruce D05765 (40.32, 175.38)	128	3.5	0.0	88	3.2	0.5
Waitapu D05964 (40.59, 175.37)	142	3.5	0.0	79	2.8	0.6
WELLINGTON						
Avalon E14195 (41.11, 174.56)	164	5.1	0.3	90	4.2	0.3
Judgeford (41.07, 174.56)	153	5.5	0.0	106	3.8	0.5
Kelburn E14272 (41.17, 174.46)	128	2.5	0.0	79	2.0	0.6
Thorndon (41.17, 174.47)	173	13.0	0.9	96	6.5	1.1
Thorndon; sheltered (41.17, 174.47)	194	12.2	0.4	130	6.2	1.0
Somes Island E14285 (41.16, 174.52)	243	4.4	0.6	137	5.2	1.0
Gracefield E14290 (41.14, 174.55)	167	7.0	0.6	102	6.2	0.5
Wainuiomata E14296 (41.17, 174.57)	165	4.1	-0.3	97	3.6	0.5
Wellington Aero E14387 (41.20S, 174.49)	268	18.3	2.6	180	18.1	2.7
Kaitoke E15011 (41.05, 175.11)	146	3.8	0.3	96	4.0	0.4
Wallaceville E15102 (41.08, 175.03)	145	4.1	0.3	87	3.5	0.5

SOUTH ISLAND

SITE (LATITUDE, LONGITUDE)	YEAR ONE STEEL	YEAR ONE ZINC	YEAR ONE ALUMINIUM	YEAR TWO STEEL	YEAR TWO ZINC	YEAR TWO ALUMINIUM
MARLBOROUGH						
Riwaka G12191 (41.06, 172.58)	95	2.3	0.0	62	1.3	0.4
Tapawera G12382 (41.23, 172.48)	97	2.6	0.4	98	1.8	0.3
Appleby G13211 (41.17, 173.06)	104	3.4	0.0	65	1.8	0.5
Nelson Aero G13222 (41.17, 173.14)	162	3.4	0.0	104	2.7	0.4
Rai Valley G13251 (41.14, 173.35)	105	3.0	0.0	63	2.0	0.6
Brancott Valley G13584 (41.32, 173.50)	58	2.3	0.0	36	1.3	0.5
Lake Grassmere G14711 (41.44, 174.9)	270	8.7	0.8	138	11.5	1.1
Lake Rotoroa F12752 (41.47, 172.35)	34	4.9	0.4	27	1.6	0.5
WEST COAST						
Westport Aero F11752 (41.44, 171.35)	375	7.2	0.0	235	6.7	0.6
Hokitika Aero F20793 (42.43, 170.59)	235	8.7	-0.8	172	5.3	0.2
Reefton F21182 (42.07, 171.52)	253	5.3	0.0	179	4.7	0.9
Greymouth F21422 (42.28, 171.12)	511	9.1	0.8	358	9.9	0.8
Otira F21851 (42.50, 171.34)	102	6.4	0.0	63	6.2	0.5
Springs Junction F22311 (42.20, 172.11)	66	3.8	0.0	40	2.0	0.6
Harihari F30153 (43.09, 170.33)	150	4.0	-0.4			
Franz Josef F30312 (43.23, 170.10)	118	9.1	0.0	71	7.9	0.3
CANTERBURY						
Hamner Forest G22581 (42.31, 172.51)	37	0.8	0.0	24	1.0	0.2
Kaikoura G23471 (42.25, 173.42)	223	4.2	0.8	149	3.7	0.8
Arthurs Pass H21951 (42.57, 171.34)	49	3.9	0.4	43	4.2	0.5
Culverden H22783 (42.46, 172.53)	76	2.3	0.0	37	1.6	0.4
Cheviot H23822 (42.48, 173.16)	108	3.8	0.0	61	1.3	0.2
Craigieburn Forest H31172 (43.09, 171.43)	25	2.5	0.4	9	0.9	0.3
Highbank H31572 (43.35, 171.44)	76	2.5	0.4	54	0.9	0.4
Ashburton H31971 (43.54, 171.45)	138	2.1	0.0	132	1.9	0.5
Eyrewell Forest H32424 (43.24, 172.17)	74	1.6	0.4	53	1.0	0.3
Christchurch Aero H32451 (43.29, 172.32)	206	2.8	0.4	123	1.7	0.5
Christchurch H32561 (43.32, 172.37)	152	2.0	0.0	83	-	0.5
Bromley H32573 (43.32, 172.42)	207	3.5	-0.4	125	2.9	0.6
Lincoln H32641 (43.39, 172.28)	175	2.4	0.0	112	1.3	0.5
SOUTHLAND AND OTAGO						
The Hermitage H30711 (43.44, 170.06)	30	3.9	0.0	23	2.4	1.1
Kelman Hut, 2450 m A.S.L (43.31, 170.22)	23	2.7	-0.6	14	3.6	0.5
Lake Tekapo H40041 (44.01, 170.28)	18	1.1	0.3	19	0.5	0.4
Fairlie H40183 (44.06, 170.50)	53	1.8	0.3	24	0.6	0.4
Twizel H40212 (44.15, 170.06)	22	1.1	0.3	20	0.6	0.5
Geraldine H41127 (44.06, 171.14)	75	1.1	0.0	63	0.8	0.4
Timaru Aero H41323 (44.18, 171.14)	144	1.8	-0.4	71	1.4	0.6
Waimate H41701 (44.44, 171.03)	74	1.8	0.7	43	1.4	-
Kurow I40742 (44.44, 170.28)	55	1.1	0.0	30	0.6	0.4
Omarama I49591 (44.32, 169.54)	17	1.4	0.0	17	0.8	0.5
Ranfurly I50113 (45.08, 170.06)	34	0.7	0.0	26	0.6	0.4
Palmerston I50147 (45.29, 170.43)	90	1.7	0.3	53	0.8	0.5
Taiaroa Head I50771 (45.47, 170.44)	239	4.4	0.3	173	3.3	0.7
Dunedin Aero I50921 (45.56, 170.12)	127	1.7	-0.3	94	1.1	0.5
Musselburgh I40951 (45.54, 170.31)	243	6.4	0.3	142	4.9	0.8
Alexandra I59234 (45.16, 169.23)	34	1.0	0.0	30	2.0	0.4
Tapanui I59921 (45.57, 169.17)	73	1.7	-0.3			
Winton I68133 (46.09, 168.20)	148	2.7	0.0	80	1.4	0.4
Gore I68192 (46.07, 168.54)	121	2.3	0.0	69	1.2	0.5
Invercargill Aero I68433 (46.25, 168.20)	253	4.0	0.3	135	3.2	0.5
Tiwai Point I68533 (46.35, 168.23)	341	15.4	1.0	235	19.5	0.8
Finegand I69273 (46.16, 169.44)	145	2.3	0.3	114	3.3	0.4

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