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Figure 8 Mackenzie River, outwash stream bed of fractured non-fluvial stones.

Figure 9 Tekapo Canal, high terrace lateral gully showing degrading embankments of fluvioglacial deposits.

3.6 Predation

Given the low numbers of *B. robustus,* a search for direct evidence of predation poses a considerable sampling problem. Few if any of the faeces collected to represent candidate predators are likely to represent the meal that happened to contain a Robust Grasshopper. As strong predator preference for one grasshopper species but not another is considered unlikely, except in terms of body size, the presence of any grasshopper in faecal material is assumed to indicate a capability of predation on *B. robustus.* Such evidence is indicated below, and included there are also two confirmed instances of predation on *B. robustus.*

The faecal examinations suggested that predation pressures on *B. robustus* are not only varied and considerable, but that such pressures extend to the later juvenile stages and adults. This is in contrast to populations of alpine grasshoppers which, in the same later stages, seemingly have few predators of any numeric consequence. The candidate predators are presented by systematics groupings.

3.6.1 Invertebrate predators include spiders and 'passenger' mites. Four observations were made of potential spider predation on five grasshopper juveniles caught in webs at monitoring sites (Sawdon Stream, Mackenzie River and Snow River). The juveniles of three species were observed caught: *B. robustus*, *Sigaus australis*, *S. minutus.* Four individuals escaped by their own efforts and one of the *B. robustus* specimens (a penultimate instar male) was deliberately freed. Although it would probably have freed itself, it seems likely that juveniles are at times killed within ground-level webs spun across stone gaps.

An undescribed species of *Erythrites* mites (Erythraeidae) (determined by Dr Graeme Ramsay) was present on the Mackenzie River population and at times was very conspicuous. The red mites attach themselves to the grasshopper body (especially the thorax) and insert feeding stylets through the exoskeleton. It is unlikely that mites ever cause a grasshopper death. Only juvenile mites are known (the adult stage is likely to be free-living away from hosts, Graeme Ramsay, pers. comm.), and November was the month of highest numbers in 1992-93. At least 31 were counted on one juvenile *B. robustus* female (final instar).

3.6.2 Reptilian predators were *Leiolopisma* sp(p) skinks. Evidence of predation is inferred from the tiny size of grasshopper fragments obtained from cat scats that also contained skinks (Sawdon Stream, Mackenzie River, Tekapo Canal). Fragment size of insects directly predated by cats is many times larger (entire insects may be included, see D below), and in none of the examined cat scats that lacked skinks were tiny fragments found. Three grasshoppers species were identifiable from fragments: *Sigaus australis, Phaulacridium marginale,* and a long-horned grasshopper, *Conocephalus* sp. Both adults and juveniles were represented.

Cumulative 1991-93 sightings of skinks at monitoring sites were as follows (parentheses show mean count per month of observations):

Tekapo Canal	21+	(3.0)
Sawdon Stream	5	(0.6)
Mackenzie River	52+	(4.6)
Snow River	58+	(4.7)
Grays Hills	1	(0.1)
Ohau River delta	0	(0.0)

Predator density was greatest at Snow River and Tekapo Canal, for these sites were several times smaller than the Mackenzie River site. However, effective predator density (the likelihood of a skink encountering *B. robustus*) could be greatest at Snow River, followed by Mackenzie River and then Tekapo Canal, since many skinks at the latter site tended to be in the gully bottom away from juvenile B. robustus habitat nearer the rim (section 3.5.6). The level of predation is unknown, and other grasshopper species are common at all three sites.

3.6.3 Bird predators included Banded Dotterel and unidentified birds, possibly one or more of the following: Oystercatcher, Harrier, Spur-winged Plover, Black-backed Gull, Magpie. Close observation of Banded Dotterel presence and behaviour was made in 1992-93, and the counts of months with positive sightings are listed below (parentheses show approximate mean bird count per month of observation):

Tekapo Canal	0	(0.0)
Sawdon Stream	5	(1.4)
Mackenzie River	1	(2.0)
Snow River (monitoring site)	0	(0.0)
Snow River (outwash fan, Fig. 5)	4	(2.0)
Grays Hills	0	(0.0)
Ohau River delta	1+	?

Collections of likely faeces were taken from the four sites with positive sightings, and most or all were assumed to be Banded Dotterel where there were few other birds of similar size to cause confusion. Only sub-samples were examined because insect contents were extremely fragmented and identifications were difficult and time-consuming. The presence of short-homed grasshoppers was confirmed, and one species was identifiable both as juvenile and adult (*Phaulacridium marginale*).

The faeces of other birds at Mackenzie River (species unknown, but see above) also yielded grasshopper identifications as follows: *Brachaspis robustus*, *Sigaus australis* and *Phaulacridium marginate*. One of two *B. robustus* records was an adult, the other a juvenile. A juvenile grasshopper fragment (species indeterminate but not B. robustus) was also found in unknown bird faeces from the Ohau River delta.

3.6.4 Mammalian predators investigated for grasshopper predation included the European hedgehog, feral house cats, ferrets and the possum. No grasshopper parts were found in faeces of the latter two (only two samples of ferret faeces were available for examination) but hedgehog and cat scats confirmed direct predation on grasshoppers.

Hedgehog faeces were found at Sawdon Stream and Mackenzie River sites only, and grasshopper fragments included at least three species: *Sigaus australis*, Phaulacridium marginale and a long-horned grasshopper *Conocephalus* sp. Numerous adults and juveniles were present in these records.

Cat scats were collected from all six monitoring sites and their environs, and three included grasshopper fragments attributed to skink prey which in turn had fed on grasshoppers (see 3.6.2 above). Separate records also gave evidence of direct grasshopper predation by cats in the vicinity of the Ohau River delta where the largest sampling of scats was carried out. The numerous fragments of insects in one scat included at least one adult *Sigaus australis*, probably female and so not much smaller than an adult female of *Brachaspis robustus*. Three wetas were in two other scats, and each was notably intact and curled as a bolus in passage through the gut (species not determined). Wetas are related to grasshoppers (they both belong to the insect group Orthoptera) and their body size range is similar. The evidence therefore points to a strong likelihood of cat predation on *B. robustus*.

3.7 Drought

The autumn of 1992 was the driest in the region for some 40 years, with a March to May rainfall in the Lake Tekapo catchment of only 40 percent of normal; and this was preceded by a December to February rainfall of only 80 percent of normal. The Grays Hills monitoring site was typically hotter and the vegetation more affected by drought than were other sites. As early as 20 January, vegetation at this site was largely dried up without a trace of green except for a few scabweed (*Raoulia*) mats, whereas at other sites a few plant species retained at least an appearance of palatability throughout the arid period. The possibility of drought mortalities in the disappearance of marked grasshoppers (see section 3.2) was therefore open to site comparisons.

There is no evidence that *B. robustus* numbers declined more at Grays Hills than at other monitoring sites in the autumn of 1991-92, and nor is there evidence of a lesser decline across sites in the non-drought autumn of 1992-93. Although there is a clear decline in the numbers of grasshoppers marked at Grays Hills in 1992-93 (Table 2), the evidence of a smaller population cannot be necessarily linked to drought (see section 3.4).

It is of greater interest that in 1993 there were several late-developing juveniles at this site, despite the earliness of Central Basin sites (see section 3.5.3). As these individuals were too advanced to belong to the new generation of 1993 juveniles, there is a possibility that delayed development represented a growth retardation due to low food quality in the autumn of 1992. Although drought-induced mortality at this site cannot be ruled out for 1992, it can be stated that **there is no evidence that drought influenced the low autumn re-sighting successes throughout all monitoring areas.**

Only one adult male *B. robustus* was found in 1993 in the wider environs of the Grays Hills site.

3.8 Hydroelectric river releases

A report to ECNZ on the Ohau River Gate 22 spill tests is reproduced as Appendix 5. Further to the February 1993 records of the report, monthly monitoring at the Ohau River delta was continued until mid-April 1993 (but without further marking of grasshoppers). In addition to the original site area, 'flood islands' where *B. robustus* individuals had initially survived were also monitored.

The combined evidence of February - April data gives a post-flood survival minimum of 34 *B. robustus* within the central 1 km of delta (compare 31 in Appendix 5, based on February data only). The composition of individuals was b adults (1 female + 5 males), and 28 juveniles (16 females + 9 males + 3 unrecorded sex). In addition to the 93 marked grasshoppers of the delta prior to 12 February 1993 (Table 1), extended observations across the total 2 km of delta by the River Recovery personnel (Richard Maloney data, pers. comm.) and across the central 1 km by the the author had included a total of 193 further sightings of non-marked grasshoppers (since 25 November 1991). This total includes 31 study site records of non-marked. Although the combined study and River Recovery counts of all delta sightings may appear large, the totals almost certainly include many repeat sightings given the systematic repetition of grid sampling by multiple observers.

The post-flood population is clearly smaller than the pre-flood population, and was more comprehensively monitored on 'flood island' refugia than had been possible over the more extended area occupied prior to flooding. Death by drowning during a flood event was proven by the dead adult female B. robustus of 19 February (see Appendix 5), and this specimen is now located as an 'evidential specimen' in the Canterbury Museum, Christchurch.

The flood event was put to good use in the *B. robustus* study in three ways:

1. A very large decline in adults (mostly marked) at the monitoring site in early 1993 could now be assessed in terms of mortality versus dispersal, because post-flood survivors were conveniently aggregated on 'flood islands'.
2. Post-flood dispersal from 'flood islands' could be observed as an outdoor laboratory experiment conveniently set up by the flood.
3. The flood provided a controlled measure of population survival in a hydroelectric river release.

The question of mortality versus dispersal was answered with graphic evidence. There must have been a near-total absence of adult female *B. robustus* in the delta in February (pre-flood) because only one is known to have survived on flood refugia. Had there been widespread adult dispersal rather than mortality prior to February, some post-flood sightings could have been reasonably expected on 'flood islands' (including a likelihood also of marked individuals). It is therefore concluded that **disappearances of adults within only 1-3 months of reaching adulthood was almost certainly a result of predation**. The recorded decline in numbers prior to February sampling was greater than in the 1992 summer, and it may be no coincidence that fewer than 20 percent of the eggs of nesting birds in the delta survived in 1992-93 given a higher predation level than in the 1991-92 nesting season (Richard Maloney pers. comm.)

The dispersal 'experiment' pointed to very limited dispersal away from flood islands in the nine weeks following the flood. The cumulative monitoring evidence shows that:

1. At one week and five weeks after the flood, only 3 B. robustus of 27 known survivors on re-visited flood islands were unaccounted for (3 adults + 0 juveniles), and the only dispersal record was 12 m for one 4th instar female.
2. At nine weeks after the flood, 20 *B. robustus* juveniles were still accounted for on the same flood islands, and there were four records of dispersal away from the islands (10 m for two penultimate males, and 15 m and 21 m respectively for a final and a 4th instar female (compare Appendix 4).

While the three non-sighted adults may also have dispersed (or have been predated), it is of interest that so many of the original flood survivors remained within their flood island areas. It is also of interest that one island (comprising atypical habitat, Appendix 5) retained its survivors when dispersal across 1 m of shaded rock slope would have returned them to a pre-flood habitat and a less spartan food supply.

The controlled measure of population survival (third objective above) is discussed in section 4.3 in the context of flood histories.

4. CONCLUSIONS AND RECOMMENDATIONS

4.1 Current status of *B. robustus* populations

It is appropriate to assess the current status of Robust Grasshopper populations using adult numbers. This restriction not only avoids the double-counting of individuals (as both adult plus juvenile) but focuses on the reproductive population.

A total of 356 marked adults (1.64 females + 192 males) and 179 observations of non-marked adults (103 females + 76 males) was recorded in the study over two years. The length of the life cycle could not be determined, but it can be shown that the data of the two study years almost certainly represent two unrelated cohorts of individuals. The two unknown parameters of the life cycle are the duration of the egg stage and the age of adult females at egg-laying. In *Brachaspis nivalis* (probably the closest relative of *B. robustus*), the adult female must pass through four stages of reproductive maturation before oviposition (Mason 1971). A similar developmental progression in the Robust Grasshopper is likely to imply a minimum life cycle of at least 2 years (note that the January emergence of 1st instar juveniles *coincides* in part with adult female recruitment, Table 4).

A 3-year life cycle is also possible:

If eggs are not laid by the first winter of the new adult female,
and if eggs require an overwintering diapause (see White and Sedcole 1991),
then the adults observed over three consecutive years will belong to unrelated cohorts because their parent generations also occurred in different years.

In either event, the use of **mean counts** for 1991-93 serves as an annual approximation of observable adults over all study sites using a monthly monitoring programme. The mean is 268 adults, and an estimate of a further 100 observable adults can be added from the 1992-93 survey o£ the primary rivers by the River Recovery programme (Richard Maloney data, pers. comm., at least 49 adult females were recorded). Only the monitoring site observations are likely to approach actual abundance, and annual estimates make no allowance for the non-observable adults in either monitoring or reconnaissance procedures.

As an attempt to assess total species abundance, observable + non-observable, allowance is further made for known sites not visited in 1991-93 (see Davis 1986; also Davis, pers. comm., Fork Stream site). Best guesses of total numbers of adults in the Mackenzie Basin in 1993 are as follows (determined according to principal distributions):

main rivers (Tekapo, Pukaki, Ohau pre-flood)	250
eastern rivers (Sawdon, Mackenzie, Snow)	280
remote from rivers (Snow River outwash fan)	250
west of canal system (Tekapo Canal, Fork River)	20
Guesstimate total	**800**

Note that the guesstimates refer to the number of individuals reaching adulthood **and not to the number of individuals surviving and present at any one time, nor to the numbers successfully breeding. It can be expected that censuses of such numbers would be very much lower.** The peak occurrence in December - January (Table 4) fell steeply by February (to 9 percent of annual sample size) before new adults could have reached a likely breeding age.

Only the population band of the Snow River outwash fan (Figure 5) can be considered as a a single breeding population. All other population distributions in the above four categories are either exceedingly small (Tekapo Canal site, Fork River, also Grays Hills) or widely dispersed with few strong population centres.

The vulnerability of the distributions is now assessed in terms of natural history and the risks of natural and induced disasters.

4.2 Natural history and vulnerability

The very cryptic behaviour of *B. robustus* (section 3.5.5) is unknown in other New Zealand grasshoppers and may point to a high level of predation in historic European times, if not formerly. It is suggested that introduced predators may have played the major role in reducing population numbers, and so in contributing to the species' present rarity status.

The large body size of the adult female is matched elsewhere in New Zealand by only the two highest altitude grasshopper species (*Sigaus villosus* and *Brachaspis collinus),* and by the migratory locust (*Locusta migratoria*). In the natural history of the Mackenzie Basin montane environment, a body weight approaching 1.5 g is likely to have been the largest invertebrate prey available over a long time, and thereby highly vulnerable. Species' vulnerability, moreover, can only be heightened when female mass is five times that of male mass; for despite greater mass and a key reproductive role, female survival relies on the same cryptic defences (as the male) against selective predation pressures.

4.2.1 The indigenous predators identified in the study are spiders, *Leiolopisma* skinks, Banded Dotterel, and possibly the Oystercatcher and/or Harrier and/or Spur-winged Plover and/or Black-backed Gull (section 3.b). Evidence suggests that the first three predators feed principally (if not wholly) on small prey individuals rather than on adult grasshoppers (especially the larger-bodied female). The primary predator of the three is undoubtedly the Banded Dotterel when resident in a *Brachaspis* area. This was noted in 1992-93 at Sawdon Stream and Snow River outwash fan where, respectively, two adults and four adults resided for a minimum of 4-5 months (section 3.6; at least one pair bred successfully).

The dotterels maintained a pattern of incessant walking and feeding across a wide search area, repeatedly crossing and re-crossing the territory daily. At Sawdon Stream, there is little doubt that this behaviour explained the dramatic drop in the number of juveniles seen and marked in 1992-93 (see Table 2), and probably also the sparseness of other grasshopper species by February 1993. Not only were total numbers extremely low at the site by February (all species), but the few recorded were more or less confined to atypical marginal grassy areas where the dotterels presumably searched less. The more open areas of terrace (Figure 7), typical of earlier grasshopper presence, had also become the observed feeding range of the dotterel. A 'clean-out' of small insect prey similarly became evident in the band of *B. robustus* vegetation across the Snow River outwash fan (Figure S).

It is possible that larger-bodied indigenous birds might also be predators, and if so, the Oystercatcher and/or Harrier and/or Spur-winged Plover and/or Black-backed Gull might account for predation on not only *B. robustus* juveniles but also on adults (section 3.6). However, no experience was available to distinguish the faecal droppings of the likely indigenous and introduced bird predators. The extent of predation by large birds may have contributed to the extreme disappearance rates of marked adult *B. robustus* (and juveniles) at Mackenzie River (Table 1).

Thus indigenous birds are likely to exert heavy feeding pressures on *B. robustus* concentrations, leading to local patchiness. As adult Robust Grasshoppers appear to escape Banded Dotterel predation, it is only the larger indigenous birds that can contribute to reductions in adult *Brachaspsis* numbers in an absence of introduced predators. It is thereby difficult to see that native birds could alone account for the apparent scarcity of *B. robustus* adults throughout a century of entomological collecting and observation. Apart from present-day larger birds, the only former Mackenzie Basin predators of *B. robustus* adults may have been the endemic ground birds, notably weka and native quail.

4.2.2 The introduced predators identified in the study were hedgehogs, feral cats and possibly the Magpie. Because Magpie observations were very localised, the above discussion on indigenous large birds and local patchiness also applies here. The presence of *B. robustus* adult fragments in unindentified bird droppings from Mackenzie River might well relate to predation by introduced birds.

Evidence of hedgehog presence was similarly localised, and there was little sign at Sawdon River in 1992-93 compared to 1991-92. It could be that heavy predation by dotterels in 1992-93 made the site less attractive (there were no resident dotterels on the site in 1991-92). The cryptic colouring and behaviour of *B. robustus* is likely to provide little protection against the olfactory senses of the hedgehog (contrast the importance of visual cues to bird predators), and heavy predation pressure appears possible. The abundance of hedgehogs in *Brachaspis* areas is unknown.

A high presence of feral cats in the Mackenzie Basin is known to be associated with the wide presence of river birds and with the historic abundance of rabbits. The feral cat is ubiquitous, and as a predator of grasshoppers is not totally dependent on the visual cues of daylight recognition. The 1992-93 heavy losses of adult *Brachaspis* in the Ohau River delta (section 3.8) can only be attributed to cats, unless large birds themselves shared in the predation of the grasshoppers. However, it must also be noted that most large birds had left the delta breeding grounds when the crash in adult Robust Grasshopper numbers occurred. Moreover, the widespread summer declines on all monitoring study sites (1991-92 and 1992-93) did not correspond with the distributions of large birds.

Two conclusions are drawn:

1. All populations of *B. robustus* are continually at risk from a suite of indigenous and introduced predators.
2. Population centres are periodically vulnerable to heavy predation on either adults or juveniles, or on both.

No centre, localised or extended, seems to escape heavy predation for long.

4.3 Risks of disaster

'Disaster' is used in the broad sense of any extreme or infrequent event that might affect the life-history and/or survival of *B. robustus*. The risks of natural and induced disasters are not easily estimated, but the historical record of extreme events is relevant to some *Brachaspis* populations. Natural disasters have included drought, 'the big feeze' of 1991, and flood, while induced disasters have included (or might in the future include) road engineering, hydroelectric engineering, hydroelectric river control, pest control, and changed land and water use.

4.3.1 Natural disasters such as the 1992 autumn drought (section 3.7) appear to have little effect if any on grasshopper survival. It was suggested that the presence of mosses and lichens in the diet may assure subsistence survival, if not for every individual, then at least for most individuals across the collective species range. A possibility of life-cycle retardation by drought has been raised in the same earlier section.

'The big freeze' of 1991 can also be overlooked. While rabbits froze to death in large numbers, the historic severity of Mackenzie Basin winters and the overwintering adaptability of endemic grasshoppers (e.g., see White and Sedcole 1991, fig. 3) suggest that 1991 survival would not have been affected.

Two natural flood disasters occurred in 1986, one from heavy rains (Mackenzie River: 11 inches in 24 h, Peter Kerr pers. comm.) and one from a cloudburst (Snow River: heavy scouring of the flood outwash zone immediately to the left of the present Snow River channel (Figure 5). The present monitoring sites are presumed to have flooded and/or have been re-formed at that time. Yet in the immediate vicinity of the Mackenzie site, Mark Davis pers. comm. readily recorded 11 *B. robustus* in January 1988 and 20 in April 1989. Whatever the immediate flood effects, populations at both rivers have survived and the present study has given some indication of population levels six years on.

The natural flood history of the three primary rivers of the Mackenzie Basin is well documented. The former Ministry of Works river flow records (obtained by courtesy of Gregory Carson of ECNZ) show the following peak flows for each river prior to the construction and commissioning of the present hydroelectric canal system:

Tekapo River (since March 1925)	390 cumecs, February 1954
Pukaki River (since July 1925)	1240 cumecs, March 1967
Ohau River (since January 1963)	475 cumecs, May 1978

The respective recording sites were 8794, 8774 and 98750, using national reference base numbering. With the exception of the Ohau River during canal construction, none of these natural flows has been exceeded by recent hydroelectric river control (see section 4.3.2). Hence, the present numbers of *Brachaspsis* in these river systems reflect a species ability to survive (or ultimately recover from) such flood levels. The numbers of natural floods over the recording periods are listed here according to selected thresholds (note that Tekapo A Powerhouse was commissioned in 1951 and the Lake Tekapo dam in 1953):

Tekapo River	exceeding 300 cumecs	3 events 1925-51
		17 events 1952-61
		0 events 1962-77
Pukaki River	exceeding 750 cumecs	4 events 1925-79
Ohau River	exceeding 400 cumecs	1 event 1963-79

It can only be concluded from the present distribution and abundance of *B. robustus* that the species appears to exhibit considerable resilience to natural disasters.

4.3.2 Induced disasters (in terms of *Brachaspis*) include the potential consequences of hydroelectric river control. ECNZ river flow records (obtained by courtesy of Gregory Carson) show the following peak flows for each river in the present hydroelectric canal system, including the years of Lake Ruataniwha construction on the upper Ohau River:

Tekapo River (since August 1977)	330 cumecs, December 1984
Pukaki River (since September 1979)	1050 cumecs, March 1982
(')ha" River (since April 1979)	760 cumecs, March 1981

The respective recording sites were 8792, 8772 and (until May 1983) 98750, thereafter Ohau site 8750 (but records missing 1983-86). Hydroelectric river controls on the Tekapo and Pukaki Rivers have not to date given peak flows exceeding the natural flood peaks cited in section 4.3.1 above. In the Ohau River, however, there were at least 73 flood events during the construction period 1979-86 that exceeded the natural flood peak of 1963-79 (above).

In terms of the Ohau River delta populations (section 3.8), the importance of these higher flood peaks to *B. robustus* survival is unknown because the profile of the river delta for that time is unknown. It is not impossible that there were higher areas than exist today, so allowing the survival of the Robust Grasshopper up to the present. If there were no areas high enough to withstand total flooding, the species may have survived there until today by means of egg survival (see below) or by advances up the delta from the Tekapo River delta area.

The level of local survival of *B. robustus* beyond a flood event is likely to be very dependent on flood timing. If waters rise over night or when weather conditions are unsuited to normal grasshopper activity, it is thought that threatened individuals may be unable to take evasive action. In contrast, when rising flood conditions favour activity, escape to ' flood islands' and river embankments may be possible for some. Thus, the timing of the controlled release of 11-13 February 1993 (section 3.8) permitted some escape and a survival rate of possibly 20-30 percent of juveniles + adults. Had the flood peak reached 430-450 cumecs, flood observations suggest it is unlikely that any 'flood islands' would have remained. Only 1 (or possibly 2) of the original 34 observed *B. robustus* survivors might have then survived because they happened to be located in river embankment areas.

Seasonal timing of a flood event might also be significant in terms of eggs surviving when the active life stages (juveniles and adults) fail to survive. This possibility could lead to a missing age cohort in the immediate post-flood period. Thus, depending on egg longevity and life-cycle length (see section 4.1), there might potentially be a year when juveniles and adults are temporarily absent from a flood zone. A missing cohort could conceiveably be re-established by variable egg longevities (e.g., see White and Sedcole 1991), but such an outcome remains to be demonstrated.

Hydroelectric and road engineering can also contribute to induced disasters. As recently as 1971-72, immediately prior to the start of canal construction by the Tekapo A Powerhouse, the Robust Grasshopper was common around the weather station within 100 m of the powerhouse (Pat Quinn, pers. comm.). Canal construction not only radically changed this landscape, but has permanently isolated the Tekapo Canal monitoring site from the Tekapo River channel. Although it cannot be known whether *B. robustus* populations on high terraces (see section 3.1.2) have had interchange with low terrace and river channel populations in recent times, there has clearly been contact in more distant times. So long as natural access paths are not blocked, isolation must be regarded as less than total. The long-term future of the small Tekapo Canal population might not have been disadvantaged by canal construction, but it has certainly not been helped.

Roading at three monitoring sites (Tekapo Canal, Mackenzie River and Snow River) provides particularly favourable habitat for *B. robustus* (see section 3.3.2), and thereby death by vehicle constitutes another species disaster risk. Although such deaths have not been proven and the gravelled tracks are infrequently used, the species' escape behaviour (section 3.5.5) is likely to expose individuals on vehicle tracks to uncommonly high risk. Vehicle transit through all six monitoring sites has been recorded, including those without formed roads or tracks.

Future changes in land and water use could also become induced disasters for the Robust Grasshopper, as in the case of forestry plantings and the spread of wilding trees (or other invading plants) in waterways and adjacent lands. The recent presumed loss of *B. robustus* from the Ahuriri River (section 3.1.1) is probably explained by the spread of willows and lupins in the river channel. Both direct and indirect influences of land- and water-use changes are possible, ranging from on-site effects to off-site effects and weather modification (if widespread forestry was developed). But whereas afforestation is a future option for the Mackenzie Basin, past options for pest control may also have held a potential for induced disaster. A scenario is now attempted to explain the historic paucity of *B. robustus* sightings, the present day status of the species and the future outlook.

4.4 Suggested scenario to explain *B. robustus* abundance

A scenario is proposed so that conservation management decisions do not overlook long-term factors additional to the ecological evidence of a two-year study. No assurance can be given that all potential factors have been identified, or that the explanatory scenario is a true history.

There can be no question that entomologists have very likely missed *B. robustus* sightings in the past because they seldom looked in the right places. Yet it is puzzling that a few more sightings of the highly distinctive adult females were not recorded in a century of collecting if the species' abundance was always similar to current levels. Only two entomologists are known to have sighted the species in earlier times (John Dugdale and Pat Quinn - see Introduction), and the 1963 Ahuriri River record is the only known instance of an enquiry from the interested public.

The puzzle needs to be considered in the context of other grasshopper species also, for entomologists additionally failed to record the Minute Grasshopper (*Sigaus minutus*) in the Mackenzie Basin for nearly 50 years after its discovery in 1928. It was rediscovered by the author at Edwards Stream in 1975, and has since been recorded by Davis 1986 as relatively common and widespread. Sightings in the present study were commonplace and locally high numbers were not unusual.

If lack of observations reflected in part a lesser presence than today, it is possible to suggest an explanatory scenario based on the collective evidence of this study. The focus of the scenario involves five elements: predation, rabbits, pest control, vegetation change and hydroelectric development.

4.4.1 Predation and pest control Rabbit numbers in the Mackenzie Basin reached outbreak levels in the late 1940's, and it was not until the early 1950's that some semblance of **pest control** was attained by an extensive poisoning campaign, e.g., see Pierce 1987. Following the subsequent amalgamations of Rabbit Boards, control effort eventually lapsed by the 1970's and, despite renewed poisoning efforts in the 1980's, a new surge in numbers reached a peak in 1990-91. Concerted and widespread poisoning campaigns, helped by 'the big freeze' winter of 1991, then brought down rabbit numbers substantially over many parts of the basin, and there has been ongoing control. The most recent poisonings of relevance to the study monitoring sites were as follows:

- Eastern basin - Sawdon Stream pre-winter 1991, Mackenzie and Snow Rivers post-winter 1991

- Central basin - land adjoining Ohau River pre-winter 1992

Pierce 1987 has shown from an 8.5 km^2 study area bordering the Tekapo River that the repercussions of rabbit poisoning on **predators** include the following effects:

- When rabbit densities are low (as in post-poisoning periods), female ferrets and juvenile cats are the predators most dependent on lizards and invertebrates

- When rabbit densities are high, fewer alternative prey are eaten by ferrets and cats

- When rabbits are winter-poisoned, there is increased predation pressure on nesting birds in the following breeding season because of a lagged decline in ferret and cat numbers (up to 6 months, Pierce and Maloney 1989)

The seasonal prey-switching of juvenile cats coincides with the annual decline in young rabbits and with the observed summer-autumn peak in invertebrate consumption (see Pierce 1987). Although few grasshoppers have been recorded in New Zealand dietary studies of ferrets and feral cats (see Fitzgerald and Karl 1979, table 2; Pierce 1987, table 4.5), the studies have been in areas with few grasshoppers.

Further to the present evidence of cat predation on grasshoppers (section 3.6), the unknown insect component of Harrier diets (see Pierce 1987, table 6.2; Pierce and Maloney 1989) leaves open the further possibility that the Harrier is an additional seasonal predator of adult *B. robustus*, **especially when** rabbit numbers have been reduced by poisoning.

Given the 1991-92 poisoning operations listed above, it is reasonable to expect that:

- Cats switched from rabbit dependence to alternative prey in the eastern and central basin site areas in 1991-92 and 1992-93 respectively

- This switch could be a strong factor in explaining the rapid and almost total disappearances of marked adults from population centres (sections 3.2, 3.3 and 3.8)

Since *B. robustus* may have overlapping age cohorts (section 4.1), it is not therefore unexpected that eastern basin population centres should still be sufficiently large to attract a second year of heavy predation (1992-93). The 1991-2 predation effects would not follow through to the next generation of juveniles and adults before 1993-94.

According to this scenario, predation pressures on *B. robustus* (and on predated birds) would have tended to be lower in the decade of increasing rabbit numbers up to 1991-92. Any marginal survival advantage to Robust Grasshoppers over such a period would then allow not only the possibility of a slow build-up in numbers beyond preceding levels, but a greater likelihood of discovery. By the mid-80's, Davis 1986 and the Protected Natural Areas Programme (unpublished data, Mark Davis pers. comm.) had shown that both *Sigaus minutus* and *Brachaspis robustus* were to be readily found with a little searching. The timing of the present study (fortuitously) may therefore have benefitted the recognition of B. robustus status at a transitional stage of reverting from higher-than-usual numbers in the 1980's to lower numbers (in the years now immediately ahead). In this respect, the scenario is open to testing in the mid-1990's. If a transition is duly demonstrated, an assumed transition from higher-than-usual *B. robustus* numbers in the 1940's to lower numbers in the 1950's would provide an historical precedent and highlight the induced status of the species' low abundance.

But besides predation and rabbits and pest control, the scenario also involves vegetation change and hydroelectric development.

4.4.2 Vegetation change The invasive spread of Hawkweeds (*Hieracium* spp.) throughout the Mackenzie Basin in recent decades has been well documented, e.g., Hunter *et al.* 1992. With the progression of desertification, a formerly diversified and stratified tussock grassland vegetation has been extensively reduced, and it is not uncommon in the 1990's to find the Minute Grasshopper in *partially degraded* areas. The tiny size of this grasshopper (in contrast to the Robust Grasshopper) makes it a much less rewarding prey for vertebrate predators, except for the insectivorous birds and reptiles such as Banded Dotterel and skinks (see section 4.2). Thus while mammalian predation may influence *B. robustus* as already discussed, it is unlikely to have had a significant effect (if any) on *Sigaus minutus* numbers. It is therefore suggested that:

- The non-recording of Minute Grasshoppers 1928-1975 was in part due to a lesser abundance of this species in the **former grasslands** of the basin.

- Increases in the numbers of Minute Grasshoppers have occurred in an absence or near-absence of prey-switching to this species when vegetation compositions and rabbit numbers changed (contrast *B. robustus*).

4.4.3 Hydroelectric development In river channels, *Brachaspis robustus* populations have further been subjected to another form of `switching'. Population and habitat adaptations to natural flood frequencies have been irreversibly switched to controlled **hydroelectric river releases**. The potential influences on species abundance are considerable, and it is noted that **the frequencies of high flows in the Pukaki and Tekapo Rivers have decreased** since canal construction. In the Ohau River, controlled high flows were extremely frequent in the canal construction years (section 4.3) but these sequences no longer occur and post-construction canal operation has **decreased the natural frequency of high flows** in this river also. It is noteworthy, however, that hydroelectric control of all three rivers has by 1993 produced no extreme high flow that exceeded the highest natural flow in the pre-canal period cited in section 4.3.

It is necessary to conclude that lessened frequencies of high flows **might** have made the primary river channels of the basin more favourable to *B. robustus* survival since the commissioning of the hydroelectric canals. Such an outcome of river control complements the other scenario factors to explain a slow build-up in numbers (and in river channel distributions?) throughout the 1980's. In this way, there may have been a greater likelihood of recent discovery in waterways that had been commonly frequented by fishers and other observers over many decades. The prospects of continuing an increasing trend are counterbalanced, however, by one very notable risk:

- A single extreme high flow in any of the three rivers, whether an intentioned hydroelectric river release or necessitated by emergency procedures, may be capable of offsetting all *B. robustus* gains from the lessened frequencies of high flows.

4.5 Recommendations

The appropriate IUCN status of *Brachaspis robustus* is 'Rare Species'. Species survival does not appear to be currently at risk, but the evidence suggests that populations in the lower Mackenzie Basin have disappeared in recent time (e.g., Ahuriri River) and that some small population centres in the central and upper basin may be at risk, e.g., Grays Hills and Tekapo Canal monitoring areas. In various locations, including river channels, there have also been numerous sightings of individuals at risk in apparent isolation; and examples have been given of a major population loss due to landscape alteration (Tekapo A Powerhouse environs) and a major population reduction due to a hydroelectric river release (Ohau River).

Induced disasters apart, no population is safe when a survival bottleneck is created by heavy predation on adult females prior to breeding. The evidence suggests that every 1.5 g of ill-fated female explains much of the species' rarity. Yet in spite of Protected Species status, no population currently has formal protection.

Four recommendations are as follows:

1. That the Snow River outwash fan population be formally protected (priority 1)
2. That the Pukaki River population be formally protected (priority 2)
3. That there be liaison between the Department of Conservation and Electricity Corporation of New Zealand Limited to optimise the cautions and timing of hydroelectric river releases (refer section 4.3 and Appendix 5) for the protection of river populations so far as is forseeable and practical.
4. That the Department of Conservation undertake a 2-year trial of feral cat control at one of three sites (Mackenzie River, Sawdon Stream or Snow River outwash fan) just before and following the December - January recruitment of new *B. robustus* adults in each of the two years, in order to compare adult female survival between the three sites and so to test the possibility of enhanced breeding success for the species.

The reasons for and implications of the first two recommendations are as follows:

- The population band near Snow River is the largest known contiguous population and is neither at risk from flood nor (it seems) at risk from the historic land use of pastoral grazing; a protection from any change of land-use is therefore strongly recommended because the effects of any change in land-use (e.g., removal from pastoral use by sheep) cannot be known.

- The Pukaki River population is the most isolated river population not in competition with other current river uses, and river channel profiles are relatively favourable to *B. robustus* survival in moderate river flows; in support, the inventory of section 2.6 has classified 43 grid locations as 'non-flooded' (or marginally flooded but with escape routes available), 1 location as (questionably) 'flooded', and 5 locations as ' non-observable'; hence, formal protection would seek to preclude other river uses that might place protected grasshoppers at risk (e.g., by limiting off-track vehicle access, wilding tree spread, weeds, and any disruptive river use or activity); and a Pukaki River protection area is likely to attract less conflict of interest than would a Tekapo River proposal.

The protection status of other selected populations is open to further recommendations, but grounds for prioritisation are difficult to establish. In the author's view, all primary population areas should be gazetted, and the Protected Species status of the Robust Grasshopper itself should be endorsed. Formal recognition is thereby granted both to population areas and to the species. A close watching brief on population trends is also recommended, with a view to proactive conservation in the future should 'hands-on' management be proven practical, e.g., cat control, subject to the outcome of recommendation 4.

4.6 Addendum, June 1994

The summer-autumn of 1993-94 (mid-December to late March) was the wettest summer in decades, and also very cool. In January, ECNZ found it necessary to spill water down the Ohau River (10-14 January, peak flow: 360 cumecs; normal flow: 0 cumecs) and the Tekapo River (9 January - 12 February, peak flow: 165 cumecs; normal flow: 0 cumecs). This was the largest release in the Tekapo River for nine years (there have been only three greater releases since canal completion in 1977), and the Obau River release followed a 401 cumec release by only 11 months (see sections 3.8, 4.3.2). Frequent rains continued into March, and in the week to 19 March, more than 11 inches of rain fell in the Sawdon Stream, Mackenzie River and Snow River catchments (at least 8 inches fell within one 24 hour period). *B. robustus* population sites are known to have been partially flooded.

In the author's view, it is certain that population losses would have occurred widely during this season. The implications for carrying out recommendation 4 are now uncertain, and a preliminary survey of population numbers at the three nominated sites is necessary to re-establish whether *B. robustus* densities remain adequate to test cat removal effects on grasshopper breeding success. Only two sites are essential for a trial.

5. ACKNOWLEDGEMENTS

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APPENDIX 1

Reconnaissance grid references for *Brachaspis rohustus* search areas

based on topographic map series NZMS 1 ('S') and NZMS Infomap 260 ('H'). Use of the latter series is essential for sites modified in the 1980's by newly commissioned hydroelectric controls.

Search area	Dates	Grid reference	No. *B. robustus*
(a) Lower Mackenzie Basin			
Ahuriri River	Feb 93	5108: 444427 - 448418	0
	Feb/Apr 93	5116: 476393 - 494378	0
Ribbonwood Creek	Feb 93	5108: 467450 - 446446	0
Avon Burn	Apr 93	S108: 425439 - 438429	0
(b) Central Mackenzie Basin			
Pukaki River	Dec 92	H38: 834623 - 839614	0
		H38: 843609 - 843608	0
		H38: 849606 - 854604	0
	Sep 92	H38: 851600 - 863585	0
	Sep/Dec 92	H38: 863584 - 885513	74
Grays Hills (Tekapo R.)	Nov 91	5109: 977678 - 973664	0
(c) Upper Mackenzie Basin			
Tekapo River	Nov 91	S100: river loop above S101: powerhouse	0
	Apr 93	S100: 090965 - 085952	1
Fork Stream	Feb 93	S100: 055975 - 073949	0
Unnamed stream	Nov 91	5100: 073964 - 076956	0

APPENDIX 2

Sample vegetation compositions of *Brachaspis robustus* population centres

in the eastern Mackenzie Basin, with some initial indications of diet. + = plant species less than 1 percent ground cover; * (or ?) = species or genus identified (or presence needs confirmation) in diet.

		Sawdon Stream	**Mackenzie River**		**Snow River**	**Snow River** Vegetation Band	
	Landform	Outwash terrace	Stream bed	Outwash terrace	Stream bed	Outwash fan	Outwash fan
	Aspect	Nil	Nil	Nil	Nil	Nil	Nil
	Slope	0.5°	0.5°	0.5°	1-5°	1-3°	1-3°
	GRASSES						
	Agrostis capillaris	5		5	0.5-1	+	+
	Aira caryophyllea	+	+				+
	Anthoxanthum odoratunr	2		+	1	+	
	Bromus tectorum		+		1-2		+
	Deyeuxia avenoides	+	+	1	+		
*	*Elymus rectisetus*	+	+	+	+	+	
	Erytheranthera pumila					+	
	Festuca novae-zelandiae			2	+	3-5	
	Festuca rubra		+	+	+		
	Holcus lanatus		+				
*	*Poa colensoi*					+	
	Poa lindsayi					+	
	Poa maniototo	+				+	
	Poa pratensis	+			+		
	Poa spp.				+		
	Rytidosperma gracilis			+			
	Rytidosperma spp.						+
	Vulpia bromoides				+	+	
	HERBS						
*	*Achillea millifolium*	+			+		
	Aphanes arvensis						+
*	*Carex breviculmis*	+			+	+	
	Carex colensoi						+
	Cerastium semiviridens	+		+			
	Cirsium vulgare				+		
	Convolvtdus fractosavosa					+	
	Crepis capillaris				+		
*	*Echium vulgare*	+	5	I	3-5		+
*	*Epilobium alsinoides*				+	+	
	Epilobium hectori				+		
	Epilobium melanocatdon		2				
*	*Epilobium rostratum*	1	+	+			
	Erodium cicutarium	+		+	+		
	Galium perpusillium						+
	Geranium sessiliflorum	+	+	+	+		
	Gypsophila australis						+
	Gypsophila sp.	+					
	Hieracium pilosella	+		1	+	40-50	30--40
	Leptinella pectinata						+

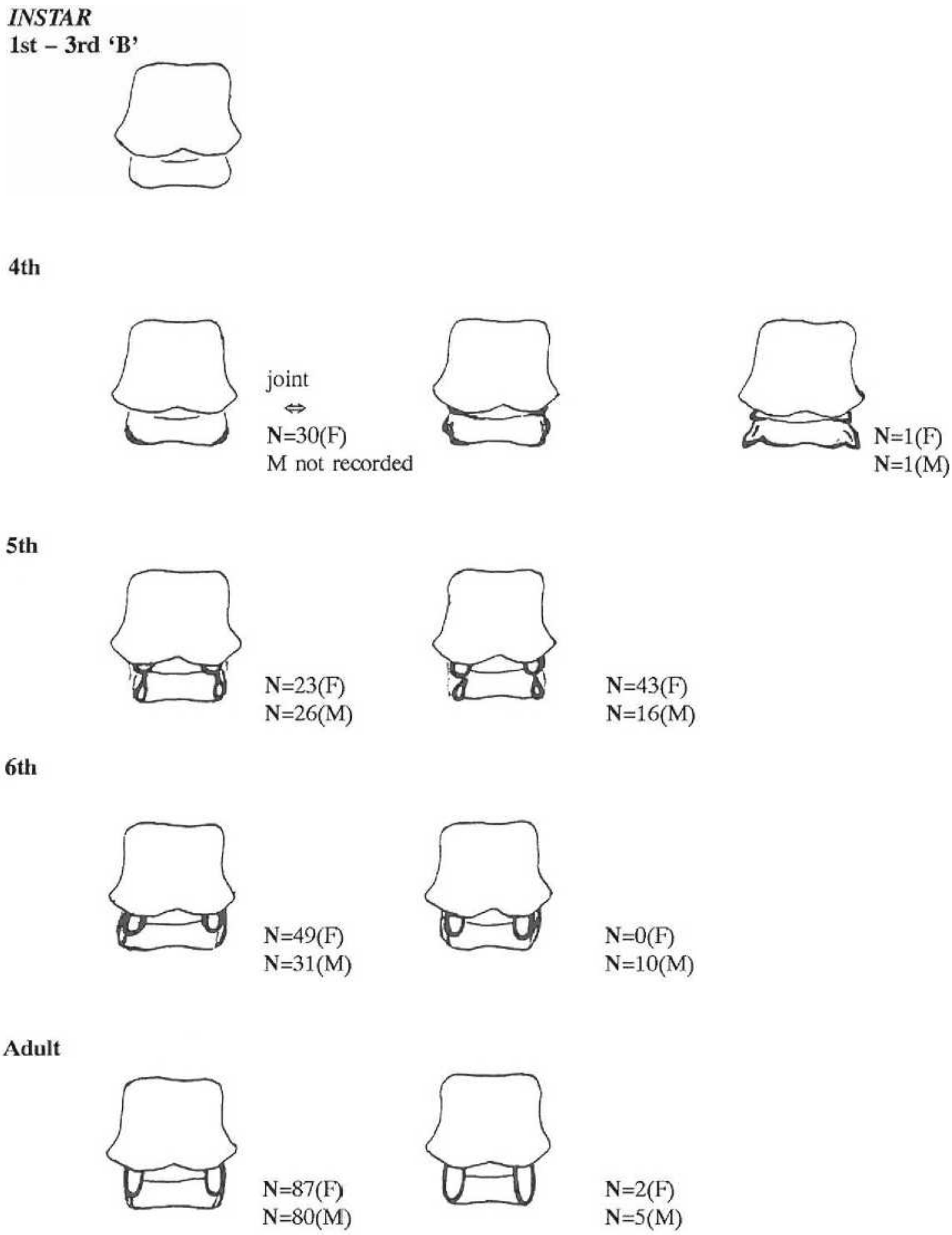
	Sawdon Stream	Mackenzie River		Snow River	Snow River Vegetation Band	
Landform	Outwash terrace	Stream bed	Outwash terrace	Stream bed	Outwash fan	Outwash fan
Aspect	Nil	Nil	Nil	Nil	Nil	Nil
Slope	0.5°	0.5°	0.5°	1-5°	1-3°	1-3°
Leptinella perpusilla						+
Luzula ulophilla						+
Myosotis arvensis	+				+	
Oxalis exilis						+
Polygonum aviculare				+		+
? *Raoulia australis*	12		+	+	+	
? *Raoulia hookeri*	+					
? *Raoulia monroi*	+		+	+	+	1
? *Raoulia parkii*					+	
Rumex acetosella	+			1-2	1	2-5
Rumex crispex			+			
Rumex flexuosus					+	
Sanguisorba minor			+			
? *Sedum acre*	+	1	10	+		
Stellaria gracilenta						+
Trifolium arvensis	+			+		+
* *Verbascum thapsus* 2 10 2-3 +						
Wahlenbergia albomarginata + + +						
SHRUBS						
Carmichaelia monroi	+				+	
Coprosma petrei						+
Discaria toumatou	1	+	2	+		
Hypericum perforatum		+		+	+	
Leucopogon fraseri						2-5
Melicytus alpinus						+
Muehlenbeckia axilaris	10	+	10	1-2		+
Pimelea pulvinaris	+				+	
Rosa rubiginosa				1		
Ulex europaeus			+			
Veronica verna			+			+
MOSSES						
* 'Brown moss'	+			+	1	5
Polytrichum spp.						
? *Racomitrium lanuginosum*	+					+
LICHENS						
? *Chondropsis viridis*	1		+	+	+	
? *Cladia aggregata*	1				+	
Cladonia spp.					+	+
Usnea spp.						+
Xanthoparmelia reptans				+	+	
BARE SOIL	5	0	9	1-5	40-50	30-40
STONES (10+ cm)	12	15	13	10-20	3	3-5
GRAVEL	50	75	36	80	1-2	5-10
	100	**100**	**100**	**100(+)**	**100(+)**	**100(+)**

APPENDIX 3

Field recognition of Brachaspis robustus instars

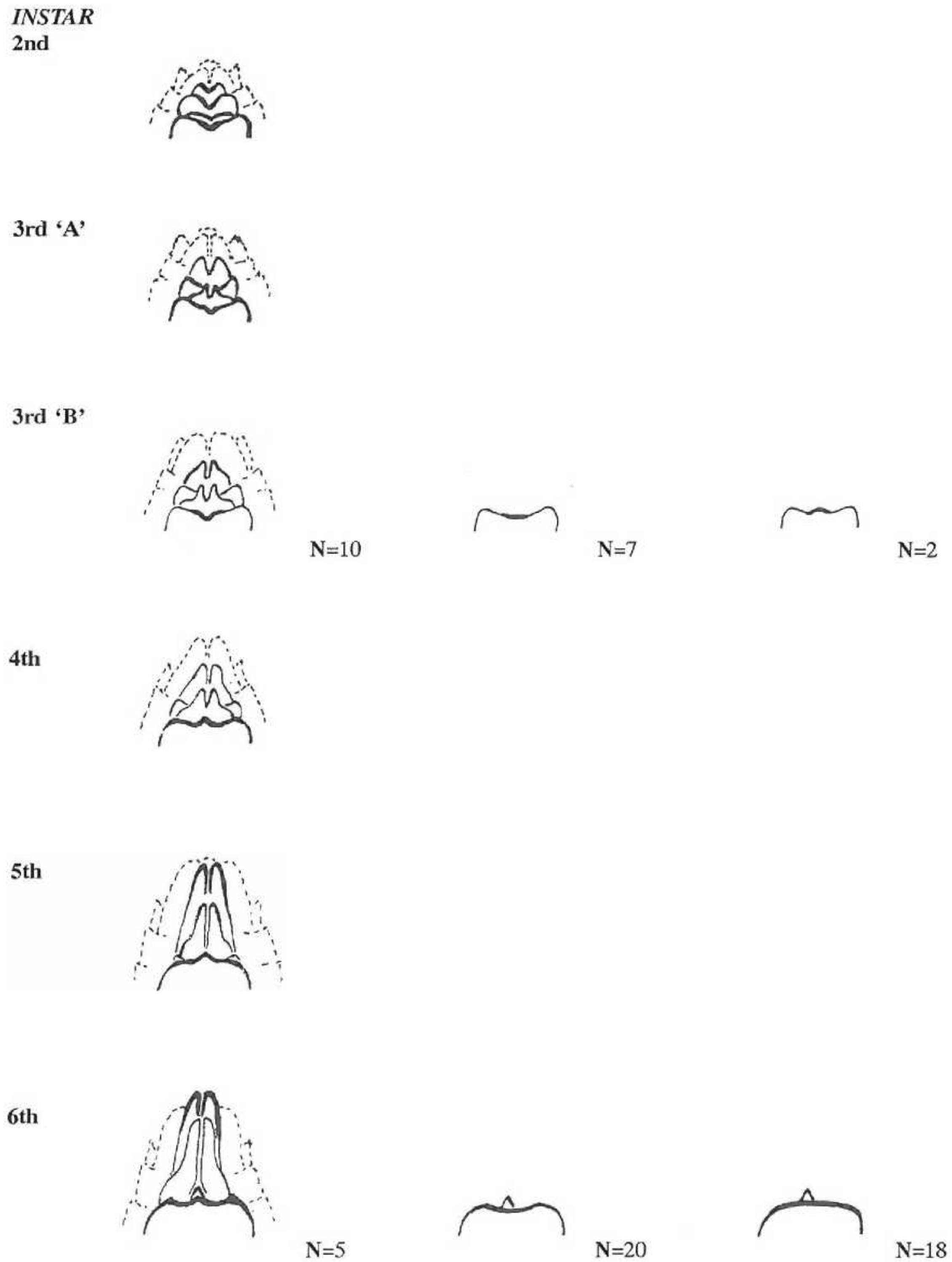
A3.1 Recognition of *Brachaspis robustus i*nstars (both sexes) by thoracic characters

The upper surface of the large segment is the pronotum, and charactcrs distinguishing the instars are shown in bold outline. Instars are not drawn to scale. N = sample sizes of variable characters; F = female; M = male.



A3.2 Recognition of *Brachaspis robustus* female instars by egg-guide characters (underside of abdomen)

There are two pairs of guides and their relative shapes and sizes should be noted (also their position relative to the tip of the abdomen, shown in background outline). Distinguishing characters are shown in bold outline but instars are not drawn to scale. N = sample sizes for variable characters.



A3.3 Recognition of *Brachaspis robustas* male instars by the underside of the abdomen

The shape of the character shown in bold outline is useful (as is its position relative to the tip of the abdomen, shown in background outline), but differences between consecutive instars are often difficult to confirm. Instars are not drawn to scale. N = sample size for character variable.

INSTAR

1st

2nd

3rd 'A'

4th

N=6

N=11

5th

N=1

N=35

6th

N=1

N=4

APPENDIX 4

Known minimum ages and minimum movements of *Brachaspis robustus*
(based on re-sightings of marked individuals)

The data are presented by growth stages and sexes, and are listed in spring-autumn sequences showing the month of marking followed by the month of (final) re-sighting. Records of overwintering individuals are asterisked.

Growth stage and sex	Longevity (days)	Months observed	Dispersal (m)
Adults			
Females			
	26	Sept - Oct	48(+)
	29	Dec - Jan	–
	31	- Jan	–
	64	- Feb	55
	113	- Apr	40
	27	Jan - Feb	–
	30	- Feb	7
	51	- Mar	–
	62	- Mar	72
	85	- Apr	35
*	253	- Sept	180
	59	Feb - Mar	30
	29	Mar - Apr	10
	29	- Apr	20
	44	- May	70
*	168	May - Oct	22(+)
Males			
	29	Dec - Jan	60(+)
	111	- Apr	40(+)
	30	Jan - Feb	85
	55	- Mar	30(+)
	224	Apr - Nov	104
Juveniles			
Females			
final instar	35	Nov - Dec	21(+)
	29	Mar - Apr	0(+)
	26	Apr - May	30
penultimate	25	Sept - Oct	1(+)
4th	16	Oct	0(+)
*	194	Apr - Oct	7
*	143	May - Sept	1(+)
*	168	- Oct	12
Males			
* final instar	190	Apr - Oct	–
penultimate	25	Apr - May	0(+)

APPENDIX 5

Effects of Gate 22 Spill Tests 11-13 February 1993

74 Toorak Ave.,
Christchurch 4.
26 February 1993

Greg Carson,
Electricity Corporation of N.Z. Ltd,
Private Bag 950,
TWIZEL.

Re: Effects of Gate 22 Spill Tests 11-13 February 1993 on populations of the protected **Robust Grasshopper (Brachaspis rohustus)** in the Ohau River delta

The Robust Grasshopper is a protected native species of the Waitaki Basin where it occurs in low numbers. It is flightless, and a scattered resident population exists in the Ohau River delta where monitoring has been undertaken since December 1991 (Department of Conservation contract S943).

The effects of Gate 22 Spill Tests were observed at the delta (below the Twizel River junction) as follows:

12 February

08:40 hours (160 cumecs at gate) prime area 'A' flooded, air temperature 9.5°C, too low for normal grasshopper activity, i.e., evasive action may have been impossible

09:25 hours (160 cumecs at gate) air temperature reaches 14.0°C, threshold for normal activity of grasshopper

09:48 hours (220 cumecs at gate) prime breeding area 'B' beginning to flood

10:00 - 11:50 hours - no observations

12:00 hours (280 cumecs at gate) prime area 'B' flooded, area 'C' crest only remains above water, prime area 'D' beginning to flood, other grasshopper areas also threatened

13:22 hours (400 cumecs at gate) area 'C' flooded, prime area 'D' (and other areas) greatly reducing in size

14:40 hours (401 cumecs at gate) only a very confined part of prime area 'D' remains above water, only a few other 'island' patches elsewhere remain dry

15:00 hours (390 cumecs at gate, assumed peak flow at delta) evidence of 'island' patches further reduced since 14:40 hours

(continued)

Gate 22 Spill Tests (continued)

13 + 19 February

Repeated searching of prime areas was carried out as well as some more extended searching. Prime breeding area 'B' is now largely overlaid by a heavy deposit of new gravels, and the population of immature grasshoppers is presumably drowned and buried. No trace found of grasshoppers on adjacent 'escape' area above high water level. However, immatures (and predatory birds!) were found on a rocky 'escape' area (atypical habitat) adjacent to prime area 'A', and a few scattered individuals survived elsewhere in isolated ones and twos.

Total survivors observed: 31 (1 adult female, 5 adult males and 25 immatures)

No estimate is available of pre-flood numbers but it appears that a heavy reduction in numbers occurred, As the surviving individuals still face risks of predation and (in some cases) extreme isolation, the above tally of known survivors does not assure a balanced sex ratio (few immature male survivors were seen) or continued survival to reproductive adulthood. There is also a likelihood that the February timing of the gate spill tests may have preceded 1993 egg-laying and/or buried or washed away any eggs already laid.

The one aggregated 'escape' area (atypical habitat, see above) is known to have at least 12 immatures and one adult male, suggesting that some grasshoppers may have escaped drowning by moving short distances to adjacent higher ground. However, aggregate survival by such escape does not appear to have succeeded elsewhere, and a flow peaking at 401 cumecs provided few escape routes to the areas of ultimate high ground. On 19 February, one dead and sun-bleached adult female exoskeleton was found nested among rocks just below high water level, This "evidential specimen" of death by a flood event will be deposited in the Canterbury Museum.

It is suggested that few if any Hobust Grasshoppers would have survived a peak flow of 450 cumecs, and that better survival and less isolation of survivors would have been possible with a flow peaking at 350 cumecs.

(continued)

Gate 22 Spill Tests (continued)

In the writer's view, the species will survive the 11-13 February spill tests, but survival is likely to be in very small numbers in terms of those that will yet succeed in reaching reproductive adulthood. It may also eventuate that with the loss of eggs already laid or on account of a flooding event that may have preceded egg-laying in the 1993 season that future adults could occur in the delta in alternate years only. As the life-cycle of the species is not yet fully understood, and may be two years (or even three years?) in duration, a full assessment of flooding impacts is not possible at this time.

E G White

Dr E. Graeme White
Private Research Consultant

cc Rob Young, DOC Twizel
Mike Cuddihy, Regional Conservator, DOC Christchurch