Photo: A. Wright

Early stages of larval feeding damage caused by *Neochetina* weevils

Photo: A. Wright

Advanced stages of larval feeding damage caused by *Neochetina* weevils

Photo: M. Julien

Healthy, undamaged water hyacinth plant

4.2 *Neochetina eichhorniae*

Egg: Eggs are more slender and are softer than those of *N. bruchi* and are usually deposited singly just beneath the epidermal layer. The eggs are visible under the epidermis, and cause a slight swelling on the leaf surface. In Argentina, eggs were laid into young central leaves, tender petiole bases or in the ligules, but in Florida eggs were concentrated in mature leaves. At 25°C females lay between 5 and 7 eggs/day, to a total of approximately 300 eggs per female. Eggs require higher temperatures than those of *N. bruchi* to develop normally, and will not hatch at temperatures below 20°C

Larva: Larval behaviour is as for *N. bruchi*. Larvae develop through three instars.

Pupa: The pupal cocoons of the two species are indistinguishable by casual observation, and the pupation behaviour is similar.

Stunted, heavily damaged water hyacinth plant following feeding by *Neochetina* spp.

Adult: Like *N. bruchi* the adult beetles are nocturnal and feed externally. Adults commence feeding within 24 hours of emergence, and the first eggs are laid approximately 6 days later. Feeding scars of the two species cannot be reliably distinguished, although there is a tendency for *N. bruchi* to produce larger feeding scars than *N. eichhorniae*. Under laboratory conditions feeding scars ranged from 0.5 mm^2 to 25 mm^2, and those of females were slightly larger than those of males. During the day adults are frequently found in the crown of the plant. The sex ratio during rearing is close to 1:1 although in field collections an excess of one or other sex has been recorded. Observations in South Africa suggest that when plants are healthy there is an excess of females while on unhealthy plants males predominate (M. Hill, pers. comm.).

4.3 Key differences

Although *N. eichhorniae* and *N. bruchi* resemble each other in appearance, life history and behaviour, they differ in a number of characteristics:

Adult size

Adult *N. bruchi* are on average larger than *N. eichhorniae*, weighing a mean of 4.53 mg (n = 143) compared with 3.49 mg (n = 34) for (DeLoach and Cordo 1976).

Morphology

Morphologically, the two species are most clearly distinguishable in the adult stage. The main morphological differences are highlighted in Figure 4.

Larval development times

In general the larvae of *N. eichhorniae* develop more slowly than those of *N. bruchi* (Table 2). Development rates vary with temperature and the quality of the plant material.

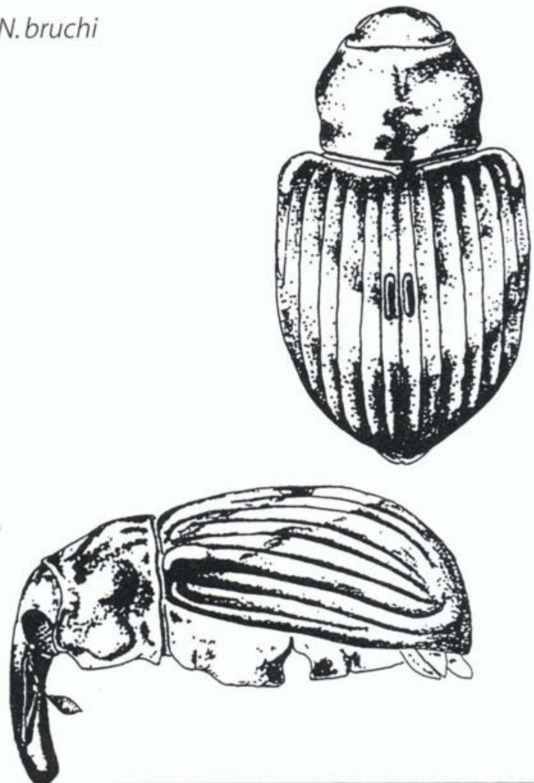
Nutrient requirements

N. bruchi are more dependent on better quality plant material for their successful development than are *N. eichhorniae* (Center 1994; Heard and Winterton, unpub. data). Consequently, the relative abundance of the two species may vary according to the quality of the host plant. Sites of poor plant quality (reflected by lower average tissue nitrogen concentration) tend to have more *N. eichhorniae*, while those of higher plant quality contain a higher proportion of *N. bruchi*.

Figure 4. Key morphological differences between adult *Neochetina bruchi* and *N. eichhorniae*

Character	*N. bruchi*	*N. eichhorniae*
Elytra markings	short and located midway along elytra	long and extending forward on elytra
	generally of equal length	generally of unequal length
Elytra furrows	broader furrows with shallow curvature	narrow furrows with strong curvature
Elytra patterning	scale coloration forms a chevron or V shape across entire elytra - this is most obvious on newly emerged adults but fades as adults age	chevron or V pattern absent from elytra

N. bruchi



Diagrams: T.D. Center

Photo: M. Day

N. eichhorniae

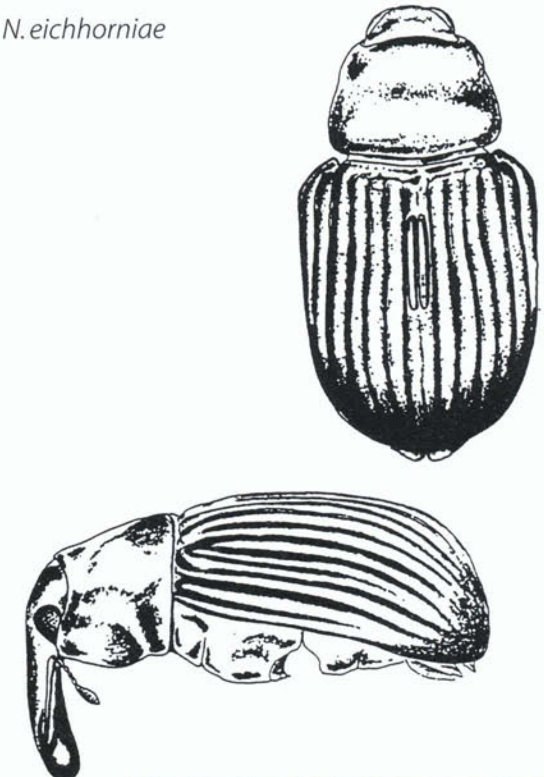


Photo: M. Day

Photo: M. Julien

Neochetina damage kills leaves, causes waterlogging and eventually whole plants die and mats sink—Gerehu Lake, Papua New Guinea

These differences influence the relative suitability of the two species as control agents under different situations. In many situations, one or other species will come to dominate under particular conditions. In general, the two species complement each other, and better control of water hyacinth often occurs when both species are present than when either species is present alone.

4.4 Impact on weed

Damage to water hyacinth comes from both the adults and the larvae. Adult feeding produces distinctive feeding scars on the leaf surface which are clearly visible and easily recognised. Larvae are rarely seen, as they tunnel and remain within the plant tissue from shortly after hatching. Their presence can be determined from the presence of streaks of necrotic tissue just beneath the epidermis of petioles.

Heavy feeding by adult weevils on the lamina causes leaves to desiccate and curl. Under pressure from this damage and from larval feeding the petioles become thin, spindly and brittle, plants become waterlogged and gradually sink. The dense mat of water hyacinth starts to fragment, with patches of water becoming visible between the plants. Areas of newest growth and smallest plants are affected first, so that colonisation by the weevils initially results in a stand of more uniform plant size and structure. The production of flowers, leaves and offshoots is reduced, and plant growth is stunted. Eventually the size of the mat decreases and the area of open water increases. As mats become smaller they are more easily flushed from the system. The speed and efficiency with which control is achieved depends, amongst other factors, on the number of insects released and their distribution through the infestation.

Chapter 5
Host-range Testing

It is crucial that any agent introduced for biological control of a weed does not itself become a pest. Agents must be able to reproduce and sustain a viable population only on the target weed and, possibly, on a number of closely related plants which are also weeds or are plants of no economic or ecological significance to the country of release. To ensure this, *Neochetina bruchi* and *N. eichhorniae* have undergone extensive host testing in numerous countries before their release (see Table 3). The plant species tested and the results of these trials are shown in Appendixes 1, 2 and 3.

The list of plants against which the insects have been tested is long and diverse (Appendix 1), covering 274 plant species in 77 families, representing a wide range of terrestrial, aquatic, economic, exotic and native plant species. The list includes plants taxonomically related to water hyacinth and plants that are taxonomically unrelated but of economic or agricultural importance. Most trials assessed the level of feeding by adults in starvation or choice tests. Some trials noted whether eggs were laid on test plants and monitored the survival of any developing larvae. On a few occasions eggs, newly hatched larvae or older larvae were placed onto plants, usually those species damaged by adult feeding, and their development was monitored.

Adult *N. bruchi* fed to some extent on 50 species of test plant (Appendix 2). All feeding was significantly less on non-target plants than on water hyacinth. The most consistently damaged plant species were those in the same family as water hyacinth (Pontederiaceae); those in the family Commelinaceae; *Pistia stratiotes* (Araceae); *Lactuca sativa* (Asteraceae); and *Brassica* spp. (Brassicaceae). *N. bruchi* laid one or several eggs on 22 plant species of which 9 (40%) were in the families Pontederiaceae or Commelinaceae. The total numbers of eggs laid on non-target plants was very low and no larvae completed development. Similarly, eggs or larvae placed on plants other than water hyacinth failed to develop and invariably survived for only a few days.

N. eichhorniae made one or several exploratory feeding scars on the foliage of 25 test plants (Appendix 3). Feeding on these plants was much less than on water hyacinth. Most feeding was barely detectable and caused no serious damage to the plants. Eggs of *N. eichhorniae* were laid on 7 species of test plant of which more than half were in the families Pontederiaceae or Commelinaceae. Most of these eggs were infertile and, if larvae hatched, they died soon after. Similarly, larvae inserted into stems of test plants did not feed and died within a short period. The only plant, other than water hyacinth, on which any larval development was observed was *Pontederia cordata* L.

(Pontederiaceae), and no larvae completed development on this plant during testing.

The host-specificity of these insects has been demonstrated during extensive host testing and confirmed by observations after their release. Despite being released widely there are no reports of these weevils seeking out and damaging plants other than water hyacinth. In Australia, feeding and larval damage were observed on *P. cordata* in the field, but only when plants of this species were placed amongst water hyacinth under heavy attack from *Neochetina* spp. (Stanley and Julien unpub. data). Damage has never been observed in other situations. Further support for their specificity comes from knowledge of the life-history of the *Neochetina* spp. The pupation behaviour of these insects, whereby they make a pupal cocoon in the roots of floating water hyacinth (Figure 3), makes it highly unlikely that any substrate-rooted plant could provide a suitable host.

Table 3. Countries and organisations which have undertaken host-specificity trials with *Neochetina bruchi* and *N. eichhorniae*. + indicates that the test list for this country is included in Appendix 1, – indicates that the test list was not available.

Country	*N. bruchi*	*N. eichhorniae*	Organisation	References
Argentina/USA	+	+[a]	United States Department of Agriculture (USDA)	1
Australia	+	+	Commonwealth Scientific and Research Organisation (CSIRO)	2
Egypt[b]	+[a]	+[a]	Department of Biological Control, Plant Protection Research Institute, Agricultural Research Centre	3
India	+	+	Indian Institute of Horticultural Research (IIHR)	4
Indonesia	+[a]	–	SEAMEO-BIOTROP	5
Kenya	+	+	Kenya Agricultural Research Institute (KARI)	6
Malaysia	+	–	Department of Agriculture Malaysia (DOAM), Malaysian Agricultural Research and Development Institute (MARDI), ASEAN Plant Quarantine Centre and Training Institute (PLANTI)	7
Thailand	+	–	National Biological Control Research Centre (NBCRC)	8
Uganda	+	+	National Agriculture Research Organisation (NARO)	9
Vietnam	+	–	Vietnam National Biological Control Research Centre , National Institute of Plant Protection (NIPP)	10
P.R. China	+	+	Biological Control Institute, Chinese Academy of Agricultural Sciences (CAAS)	11
Zimbabwe	+	+	Plant Protection Research Institute (PPRIZ)	12

[a]test results not available for inclusion in Appendixes 2 and 3;
[b]weevils not released in Egypt.
References: 1 DeLoach (1976); 2 Harley (1975), Forno and Wright (1990); 3 Y.H. Fayad, pers. comm.; 4 Jayanth and Nagarkatti (1987), Nagarkatti and Jayanth (1984); 5 S.S. Tjitrosoedirdjo, pers. comm.; 6 G. Ochiel, pers. comm.; 7 Sastroutomo et al. (1991); 8 B. Napompeth, pers. comm.; 9 Ogwang and Molo (1997); 10 Cam (1997); 11 Ding et al.(1998); 12 G. Chickwenhere, pers. comm.

In light of all this evidence, releases of these *Neochetina* spp. into new countries can now be carried out without undertaking exhaustive host testing. Testing, including both multiple choice and no-choice oviposition and larval development trials, should still be carried out on native members of the family Pontederiaceae, if they have not already been tested. By utilising the host-specificity test results already available, the time and cost associated with a release program can be greatly reduced.

Chapter 6
History of Introductions

Based on the results from the various host range trials, these *Neochetina* species have been widely released throughout the distribution of water hyacinth (Julien and Griffiths 1998). *N. bruchi* has been released in 27 countries and *N. eichhorniae* in 30 (Figures 5 and 6). The original source of material for all these releases was Argentina. In most countries, both species have been released and at least one has established and become widespread. There is confirmation that the insects are having a significant impact on the weed in the following countries: Argentina (DeLoach and Cordo 1983); Australia (Wright 1979, 1984); Benin (van Thielen et al. 1994); India (Jayanth 1987, 1988); Papua New Guinea (Julien and Orapa, unpub. data); Republic of South Africa (C. Cilliers, pers. comm.); Sudan (Beshir and Bennett 1985); Tanzania (R. Mohamed and G. Mallya, pers. comm.); Thailand (Napompeth and Wright, unpub. data); Uganda (Ogwang and Molo 1997; J. Ogwang; pers. comm.), United States of America (Goyer and Stark 1984; Center 1994; Cofrancesco 1984) and Zimbabwe (G. Chickwenhere, pers. comm.). In many other countries where releases have been made it is too soon to expect any observable effect.

As well as the recorded introductions, the *Neochetina* weevils have reached some countries by natural dispersal or by unrecorded means (see List D in Julien and Griffiths (1998)).

Figure 5. The origin of *Neochetina bruchi* for each country in which it has been released. Countries in bold type are those where the agent is known to have established. The year of first introduction is given in brackets.

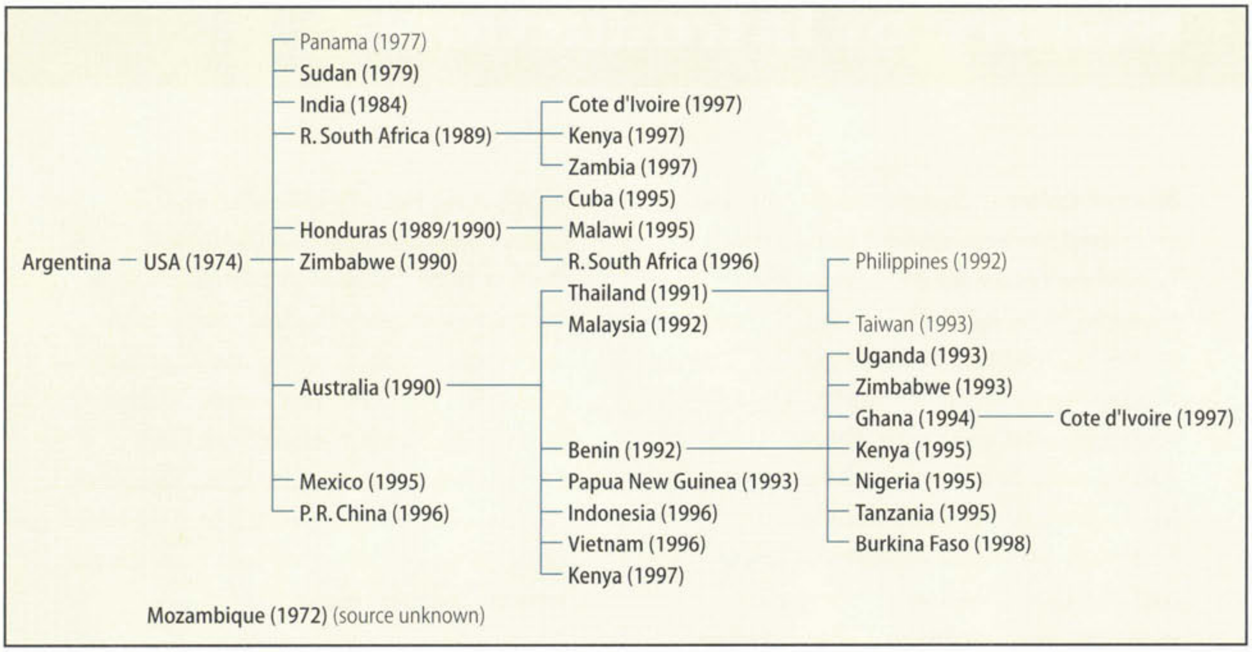
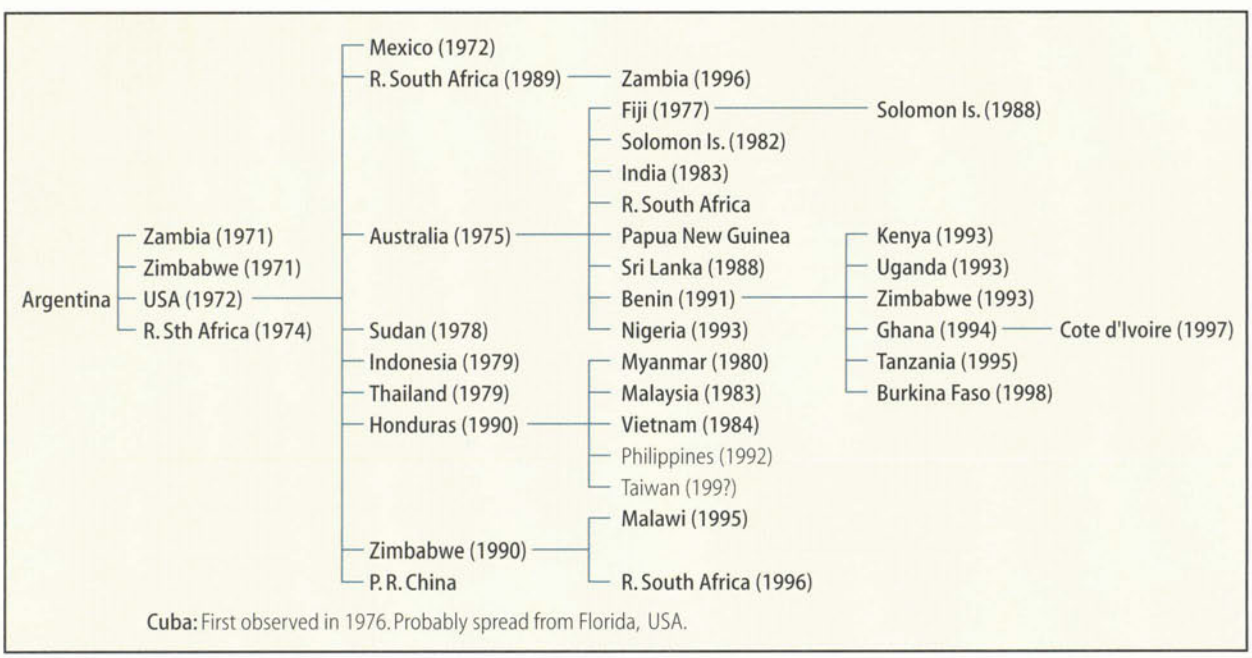


Figure 6. The origin of *Neochetina eichhorniae* for each country in which it has been released. Countries in bold type are those where the agent is known to have established. The year of first introduction is given in brackets.



Chapter 7
Rearing and Distribution

The practices suggested here have been used successfully to rear and release *Neochetina* spp. Alternatives undoubtedly exist that may sometimes better suit particular localities or conditions. In some situations, what is possible or practical may override what is desirable. The rearing times and production figures are indicative only and will vary under different circumstances, according to climate and the condition of the host plants.

7.1 Mass rearing

The aim of any mass rearing program is to produce the maximum number of good quality insects for minimum labour and resource costs. Release of high numbers of insects will increase the likelihood of establishment and reduce the time between release and control of the weed. Despite the advantages of releasing large numbers of insects, agent quality should always be more important than agent quantity.

Rearing techniques are similar for the two *Neochetina* spp., but it is desirable to keep the two species separate during rearing, at least at the early stages in a biological control program. This will ensure that the establishment and success of each species in the field can be more easily monitored and assessed. While *N. bruchi* prefer healthy, young plants, *N. eichhorniae* perform better on older plants. Therefore, there is a risk that, in a mixed culture, *N. eichhorniae* will come

Photo: M. Julien

Photo: M. Julien

The pool should be covered with water hyacinth plants so that the water surface is not visible. The pool on the bottom is well stocked while that on the top is too thinly stocked

to dominate as plants age, and *N. bruchi* may eventually decline in numbers. Colonies can be kept isolated by distance (a distance of several hundred metres between colonies should minimise the risk of invasion between sites), and by placing gauze covers over the rearing containers at night to prevent dispersal by adults. Adult dispersal will also be minimised by