Exotic pests and biological control in New Zealand broadacre pasture; success hoisted by its own petard?

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Pasture production is almost at horticultural intensity

Half of NZ comprises improved pasture

This talk relates to an exotic weevil species…

The Argentine stem weevil (ASW) (*Listronotus bonariensis*)

Listronotus bonariensis; 3-4 mm long

The stem-mining larvae cause severe damage to improved pasture…

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Successful biological control was achieved via the thelytokous braconid wasp *Microctonus hyperodae* (solitary and parthenogenetic)

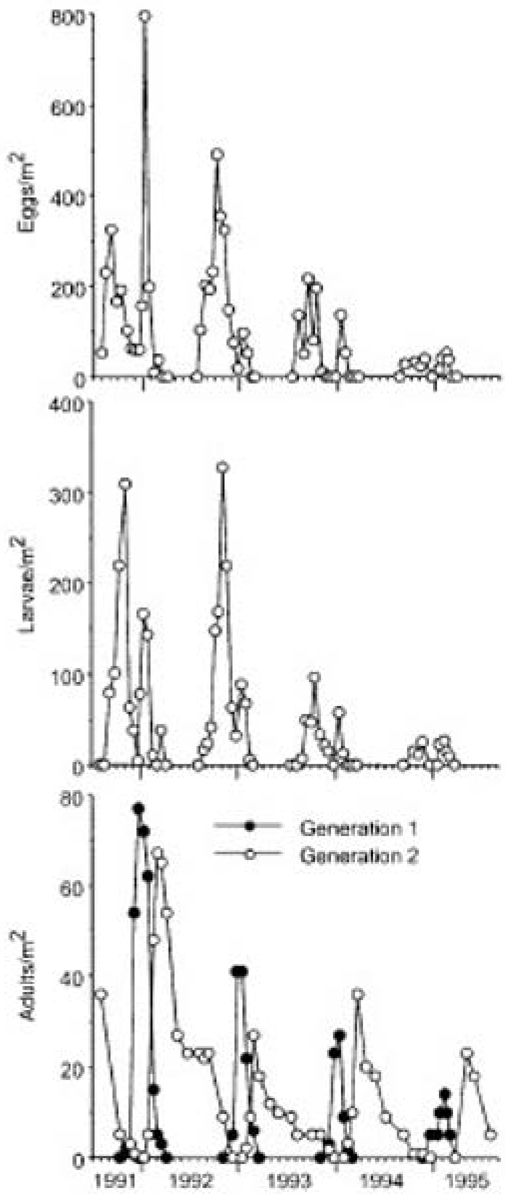
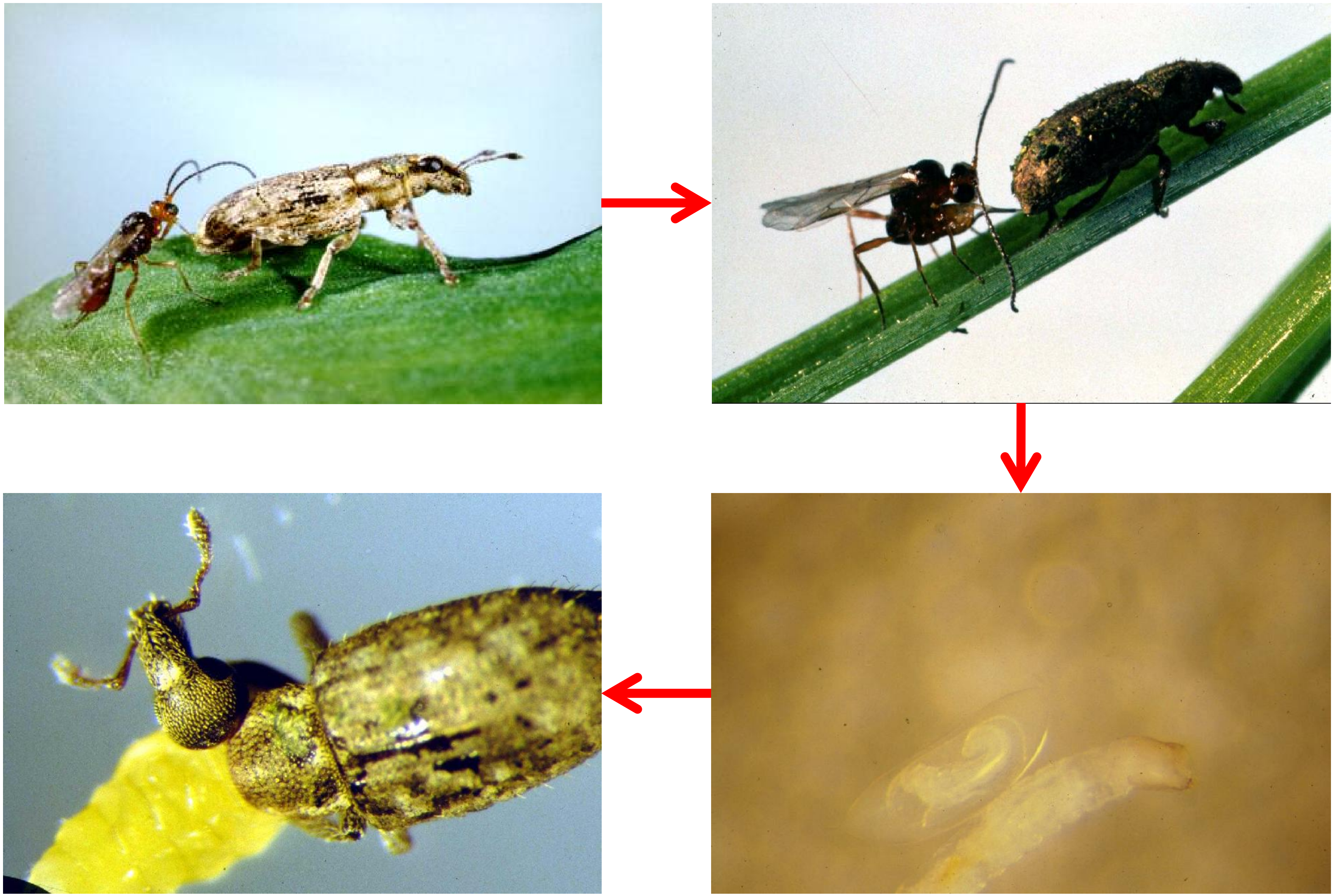


Fig. 5. Temporal trends in *L. bonariensis* at site 12, over 4 yr after the establishment of the parasitoid *M. hyperodae*.

Microctonus spp. life cycle …



So did we do something special; were we brilliant?

Probably not…

Maybe New Zealand's lack of grassland ecosystem complexity played a major part…?

New Zealand pasture is a very simple ecosystem…

- Partial transplant of European grassland ecosystems; largely two spp. ryegrass + clover
- Very low biodiversity
- Minimal niche competition
- Uniformity = lack of granularity or refugia
- Absence of significant indigenous control agents in the field or surrounding areas etc. (parasitoids, spiders, predators etc.)

The simple and species-poor NZ ecosystem…

European hill pasture

English meadow

American prairie species

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NZ's very simple pastoral ecosystems…

Result in…

- Minimal biotic resistance to invasive exotic spp.;
- Enormous abundance of host plant material and no biotic push-back
- Hence the very severe pest outbreaks; densities far higher than native range

Why parasitoids successful …

- The very thing that allowed pest species to thrive, similarly benefited biocontrol
- They too have thrived in vacuum and built up to very high populations…
  - peak parasitism 80-90% in very high host densities
  - extremely high densities (<400 m^{-2})
- Very different from native range; indeed doubtful if any evolutionary history at these levels

The big question now…

Is the success of *M. hyperodae* suppression against ASW in New Zealand failing?


By 2011 Popay *et al.* had noted that something awry
ASW autumnal damage in Taranaki, New Zealand

Anecdotal reports of large populations of ASW now being found

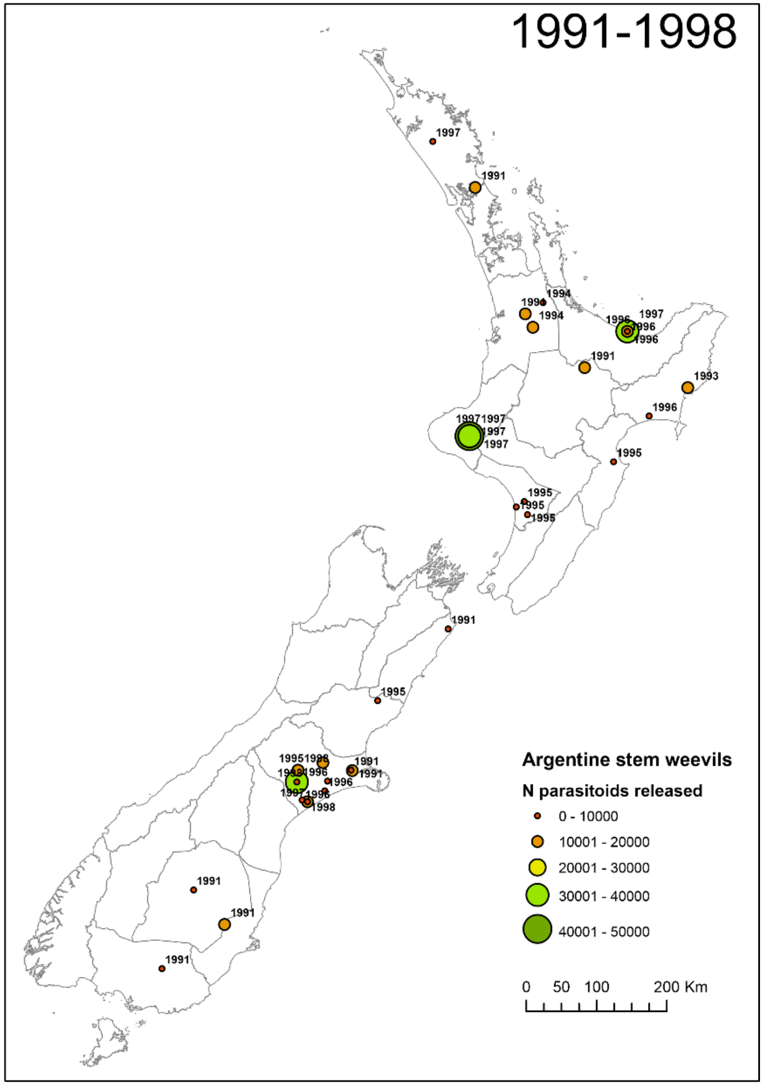
A longitudinal study has commenced…

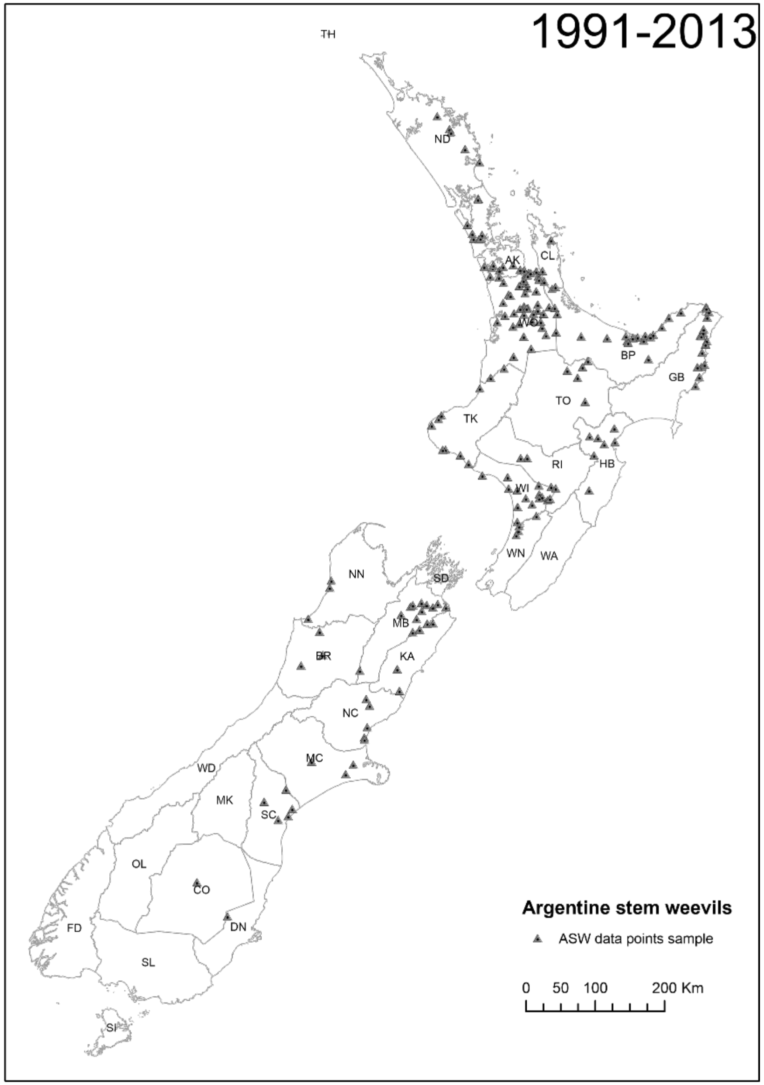
About 1.5 years ago a major effort to assemble time-series data on ASW parasitism levels to look for trends in parasitism levels commenced

This involved:

- searching databases
- data-mining from published material
- dissection of weevils from frozen specimens
- new sampling regimes

M. hyperodae was released in 1991 and very detailed records were kept etc.

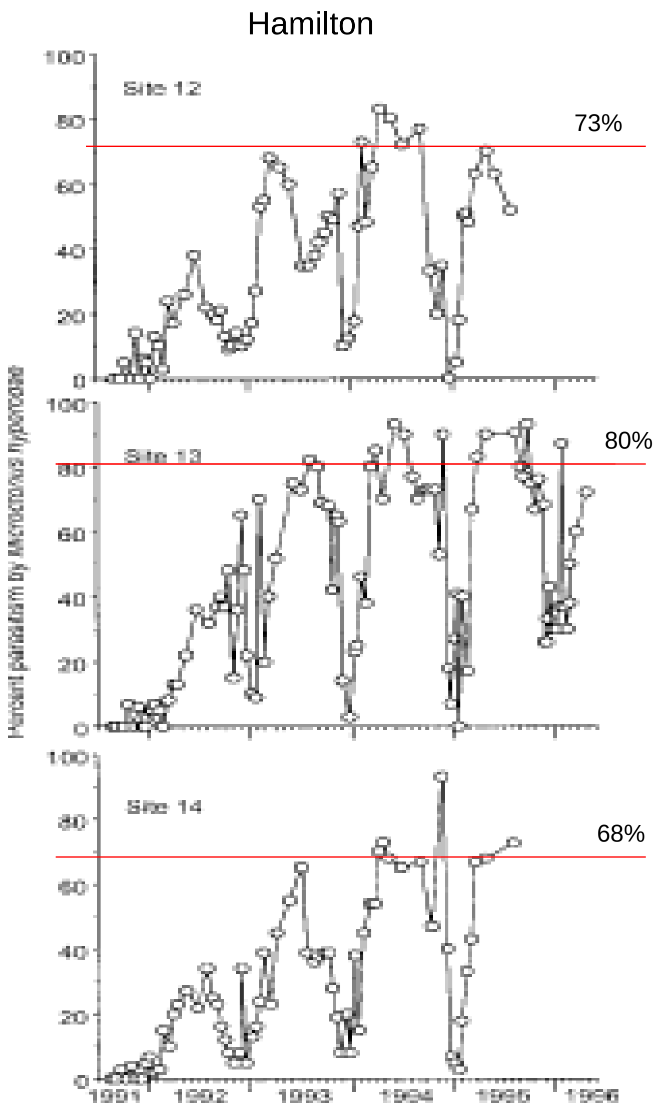




Databases mined

Type	Site	Island	Region		Latitude	Longitude	NZMGX	NZMGY	Crosby	Year released	Date Released	Nreleases	Nsites	Nparasitoids
Research	Wellsford	NI	Auckland	north Auckland	-36.167	174.467	2642538.905	6558297.922	AK	1991	11 Apr - 17 Sep 1991	7	1	12960
Research	Ruakura	NI	Waikato	central Waikato	-37.769572	175.310648	2713762.079	6378860.671	WO	1991	11 Apr - 17 Sep 1991	7	1	12960
Research	Reporoa	NI	Waikato	central Waikato	-38.433	176.3	2798153.763	6302530.645	TO	1991	11 Apr - 17 Sep 1991	7	1	12960
Research	Lincoln (1)	SI	Canterbury	mid-Canterbury	-43.632917	172.472633	2467453.765	5730370.041	MC	1991	11 Apr - 29 Jul 1991	2	1	14940
Research	Lincoln (2)	SI	Canterbury	mid-Canterbury	-43.627697	172.450302	2465647.93	5730938.429	MC	1991	13 Aug and 17 Sep 91	2	1	4520
Research	Hororata	SI	Canterbury	mid-Canterbury	-43.526646	171.954467	2425494.122	5741783.186	MC	1991	11 Apr - 17 Sep 1991	7	1	19460
Research	Sutton	SI	Otago	central Otago	-45.56636	170.12606	2285574.752	5511800.807	DN	1991	10 and 31 Oct 91	2	1	15370
Research	Ophir	SI	Otago	central Otago	-45.10955	169.58753	2241474.686	5560930.843	CO	1991	31-Oct-91	1	1	5770
Research	Gore	SI	Southland	Southland	-46.0974	168.945852	2196428.585	5449000.983	SL	1991	None			0
Research	Ward	SI	Malborough	coastal Malborough	-41.818408	174.12976	2603851.243	5931462.648	KA	1991	15-Aug-91	1	1	840
Commercial	Alford forest	SI	Canterbury	Mid-Canterbury	-43.619674	171.515014	2390158.277	5730912.035	MC	1995	11.5.95	2	4	20000
Commercial	Alford forest	SI	Canterbury	Mid-Canterbury	-43.619674	171.515014	2390158.277	5730912.035	MC	1998	3-Apr-98	1.5	3	15000
Commercial	Eiffelton	SI	Canterbury	Mid-Canterbury	-44.023928	171.673683	2403675.007	5686219.503	MC	1995	28.3.95	2	4	20000
Commercial	Eiffelton	SI	Canterbury	Mid-Canterbury	-44.023928	171.673683	2403675.007	5686219.503	MC	1997	12-Sep-97	1	2	10000
Commercial	Eiffelton	SI	Canterbury	Mid-Canterbury	-44.023928	171.673683	2403675.007	5686219.503	MC	1998	11-Jun-98	1	2	10000
Commercial	Iniskillan	SI	Canterbury	North-Canterbury	-42.74151	172.920189	2503471.769	5829531.554	NC	1995	12.5.95	1	2	10000
Commercial	Valetta	SI	Canterbury	Mid-Canterbury	-43.77035	171.489319	2388387.474	5714137.694	MC	1995	15 May and 10 Jul 95	4	8	40000
Commercial	Valetta	SI	Canterbury	Mid-Canterbury	-43.77035	171.489319	2388387.474	5714137.694	MC	1998	3-Apr-98	0.5	1	5000
Commercial	Hinds	SI	Canterbury	Mid-Canterbury	-44.000965	171.577553	2395925.93	5688643.966	MC	1996	21.03.96	1	2	5000
Commercial	Rakaia Is.	SI	Canterbury	Mid-Canterbury	-43.7644	172.032799	2432130.886	5715446.628	MC	1996	16.04.96	1	2	10000
Commercial	Pendarves	SI	Canterbury	Mid-Canterbury	-43.889109	171.983215	2428306.735	5701544.593	MC	1996	21.3 1996	1	1	5000
Commercial	Gisborne	NI	Poverty Bay		-38.628404	177.998031	2945044.174	6274025.641	GB	1993	14.07.93	1.5	3	15000
Commercial	Waikato	NI	Waikato		-37.61964	175.59237	2739057.392	6394803.071	WO	1994	04.10.94	1	2	10000
Commercial	Waikato	NI	Waikato		-37.93846	175.43798	2724457.368	6359823.228	WO	1994	01.09.94	2	4	20000
Commercial	Feilding	NI	Manawatu	Manawatu	-40.33602	175.43351	2716727.984	6093810.044	WI	1995	31.03.95	1	2	10000
Commercial	Bulls	NI	Manawatu	Parewanui	-40.243109	175.244583	2700944.735	6104548.74	WI	1995	10.7.95	1	2	10000
Commercial	Bulls	NI	Manawatu		-40.169692	175.374702	2712231.092	6112406.447	WI	1995	15.7.95	1	2	10000
Commercial	Hastings	NI	Hawkes Bay		-39.62116	176.837799	2839406.374	6168884.678	HB	1995	31.03.95	1	2	10000
Commercial	Wairoa	NI	Hawkes Bay		-39.016783	177.38829	2889913.251	6233729.349	HB	1996	14.03.96	0.5	1	5000
Commercial	Whakatane	NI	Bay of Plenty		-37.947717	176.971153	2859079.702	6353960.323	BP	1996	06.06.96	4	8	40000
Commercial	Whakatane	NI	Bay of Plenty		-37.947717	176.971153	2859079.702	6353960.323	BP	1996	24.07.96	1.5	3	15000
Commercial	Whakatane	NI	Bay of Plenty		-37.947717	176.971153	2859079.702	6353960.323	BP	1996	29.08.96	2	4	20000
Commercial	Whakatane	NI	Bay of Plenty		-37.947717	176.971153	2859079.702	6353960.323	BP	1996	30.10.96	1	2	10000
Commercial	Whakatane	NI	Bay of Plenty		-37.947717	176.971153	2859079.702	6353960.323	BP	1997	15.4.97	3.5	7	35000
Commercial	Taranaki	NI	Taranaki		-39.349166	174.440489	2634188.986	6205212.807	TK	1996	09.10.96	3.5	7	35000

Data mining… high overwintering parasitism levels in the1990s



3. Temporal trends in the incidence of parasitism by rodae in the adult stage of *L. bonariensis* over 4 to 5 yr lease of the parasitoid at sites 12–14.

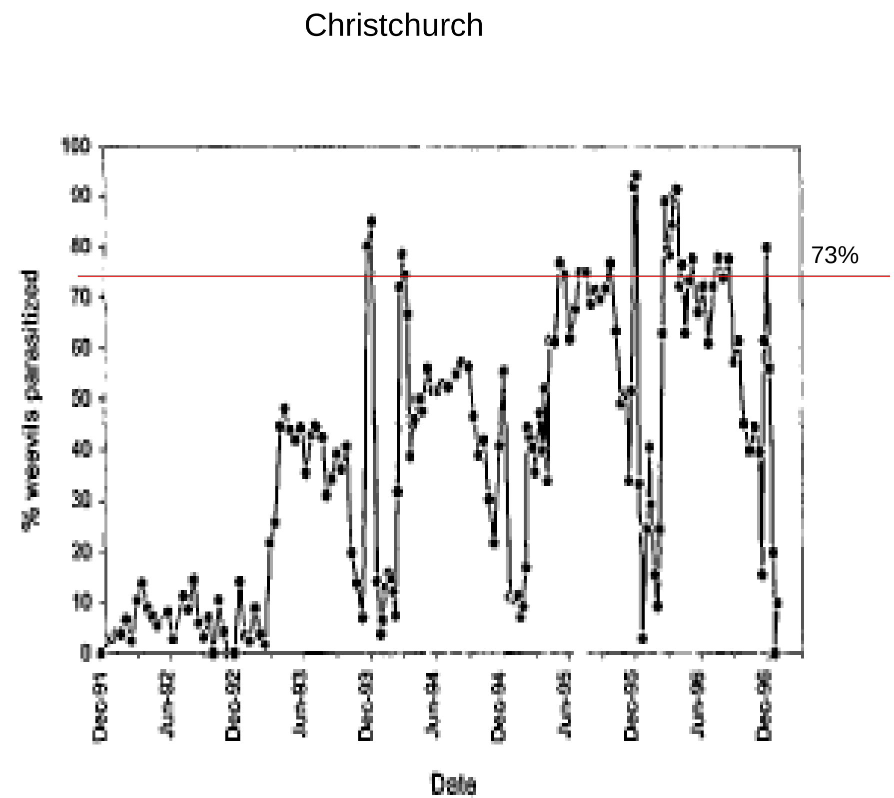
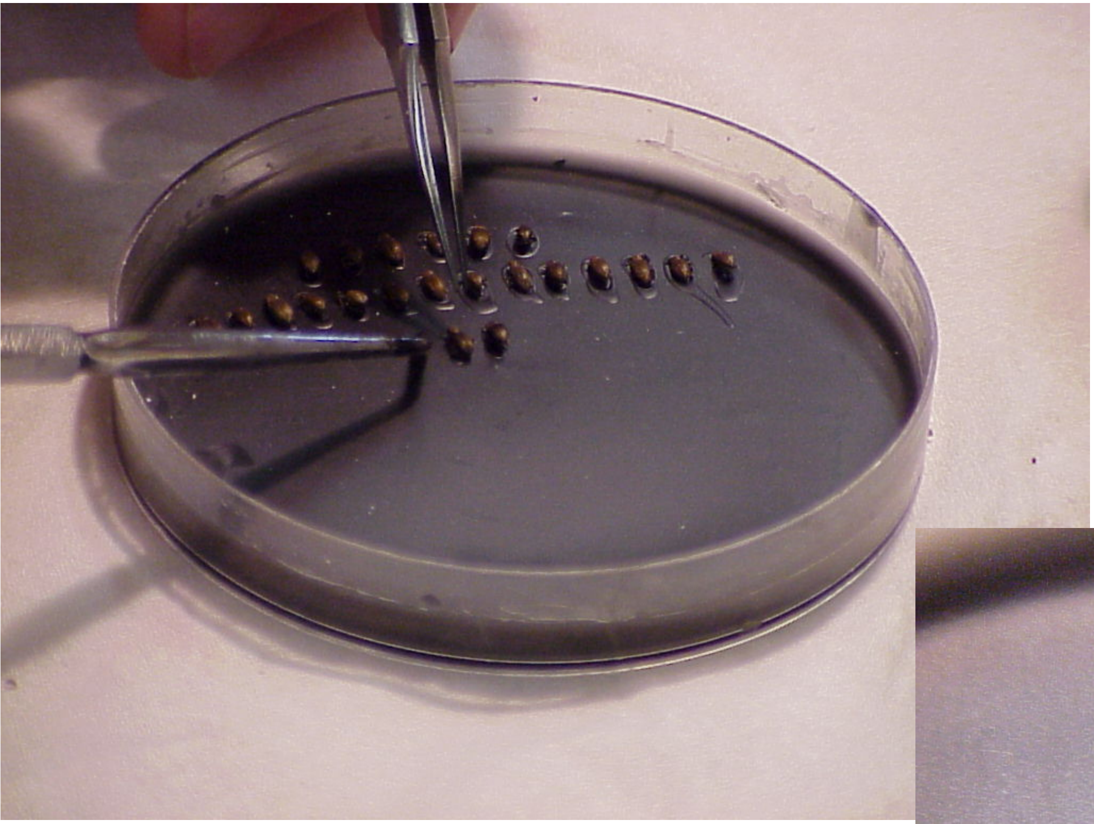
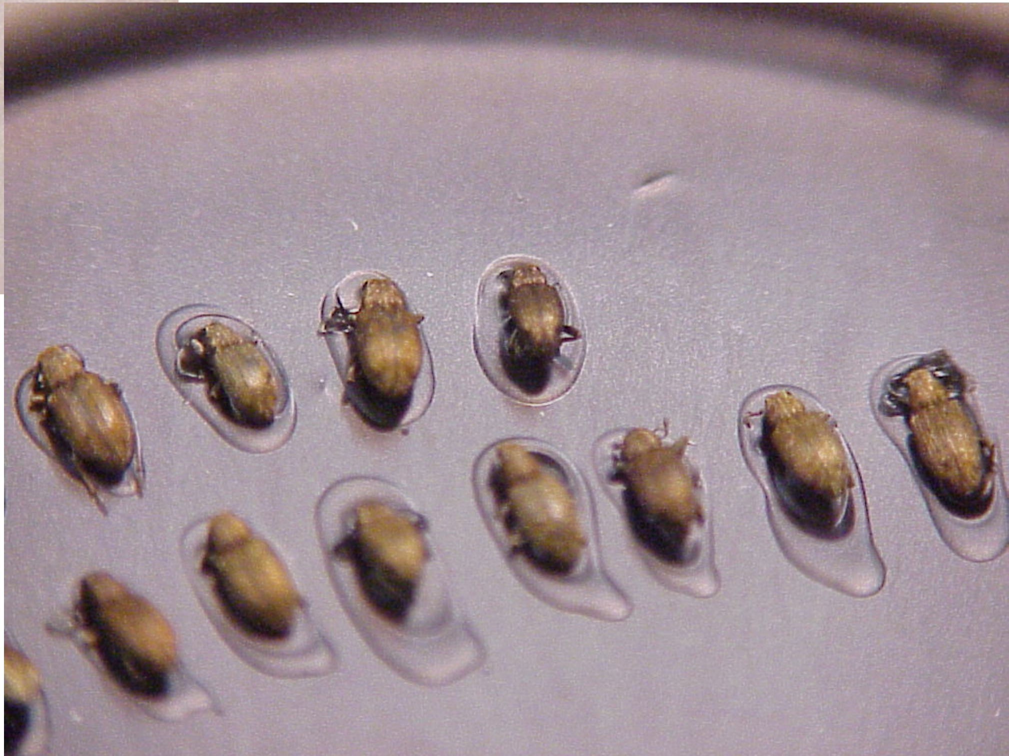


Fig. 1. Percent parasitism at Lincoln of *L. bonariensis* by *M. hyperodae* from December 1991 through December 1996.

Data mining from old frozen specimens (-40ºC)

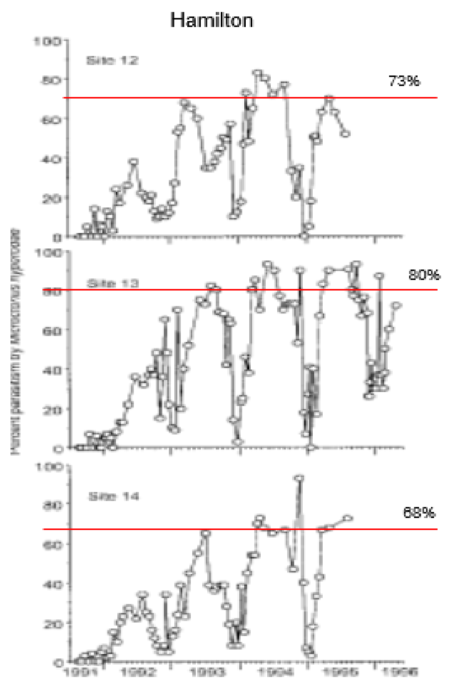




Collection of current parasitism levels

Particular attention was paid to overwintering levels of parasitism as…

- Levels of parasitism stable at this time due to diapause
- There were abundant data available for this time of the year



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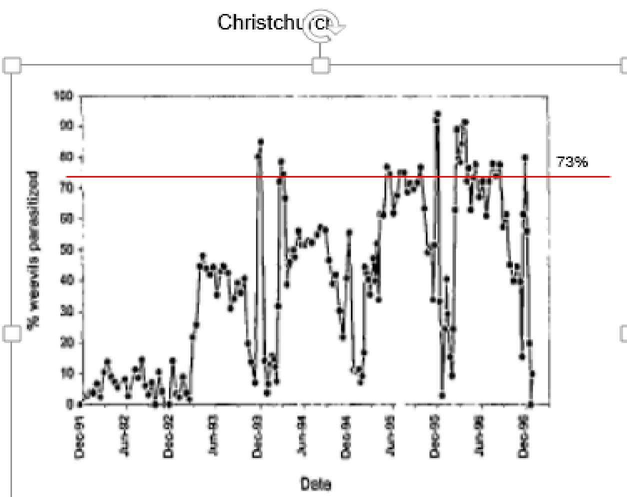

Fig. 1. Percent parasitism at Lincoln of *L. bonariensis* by *M. hyperodae* from December 1991 through December 1996.

The results of this study have been striking…

Observation…

- Overwintering parasitism was found to have dropped from c. 71% to c. 15%

A small study…

- Conducted in 2014 to try to corroborate overwintering reductions
- Parasitism measured weekly from a typical New Zealand pasture
- These results then compared to 1990s seasonal parasitism levels
- Pattern of annual fluctuations were also compared

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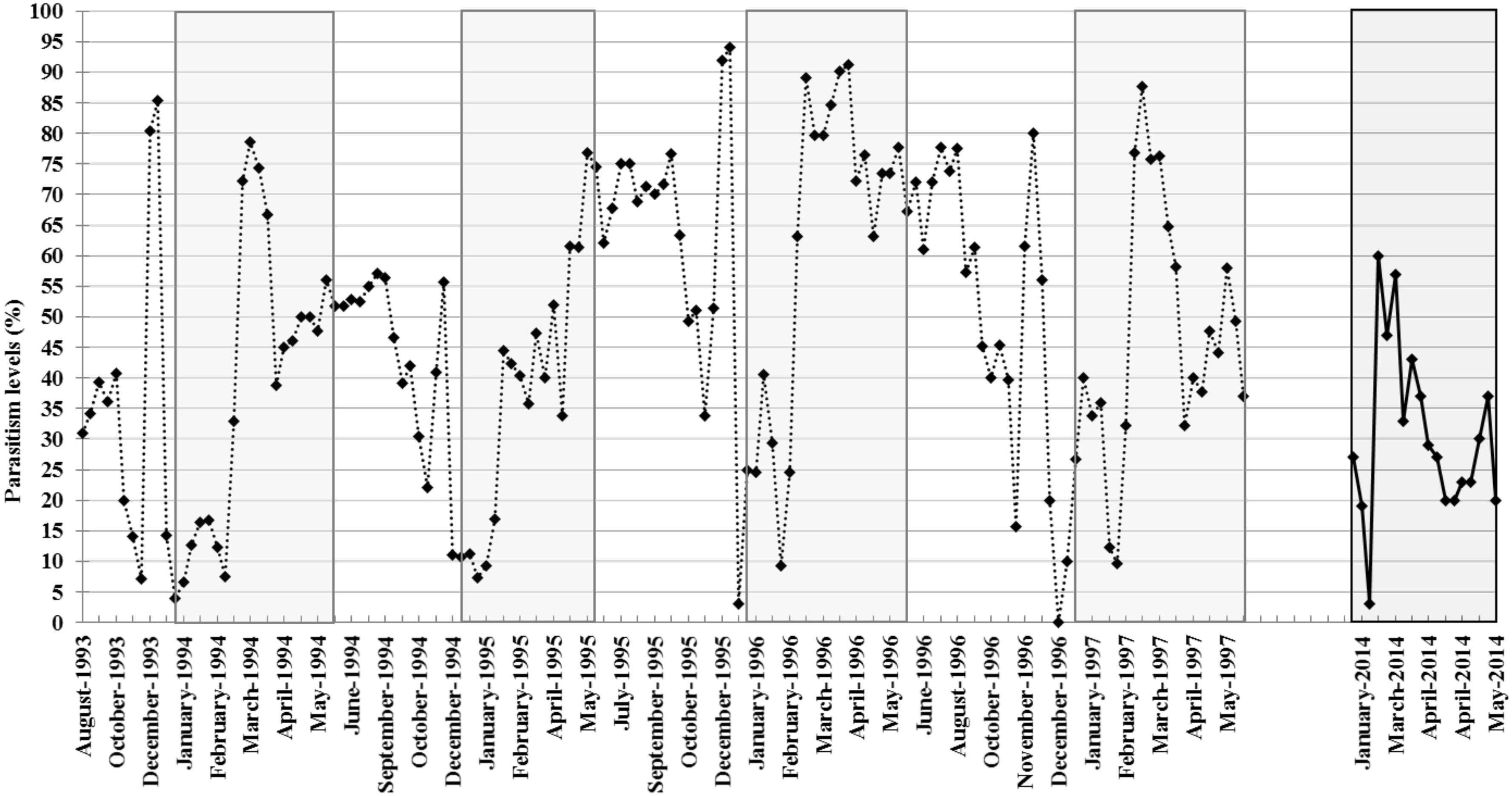
Pattern and levels of summer parasitism fluctuation 1990s and 2014



Thus…

- Both the overwintering and summer parasitism levels have shown significant decline since the 1990s
- These declines are sufficient to collapse biological control irrespective of density dependencies

So what is going on? Classical Biocontrol is robust because…

- Control agents can co-evolve with a pest (BC arms race)
- Spatial or temporal refugia (ecosystem granularity) conserves pest-susceptibility
- Diverse agro-ecosystems offer wide range of natural-enemy guilds

Classical biocontrol failure v. rare

- Only one example in literature
- Larch sawfly controlled for 27 years by an ichneumonid, then failed through encapsulation of the parasitoid's eggs
- So why the declining efficacy of *M. hyperodae*?

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However, in NZ pastures things v. contrary…

- Very high continuous selection pressure on *ASW* for 20 years
- *M. hyperodae* parthenogenetic; cannot co-evolve. Sexually reproducing ASW can
- NZ pastures lacking spatial or temporal refugia
- NZ pastures species-poor; no natural-enemy guilds to contribute to suppression.
- Only one control agent: *M. hyperodae*

So why the declining efficacy of *M. hyperodae* in *L. bonariensis*? (i)

- Ironically seems that reason for success maybe the making of failure
- Failure of *M. hyperodae against* ASW very rare example; by same token New Zealand pastures very unusual
- If it is to fail anywhere, why not in New Zealand pastures?
- Could happen to other New Zealand pasture biocontrols; clover root weevil?

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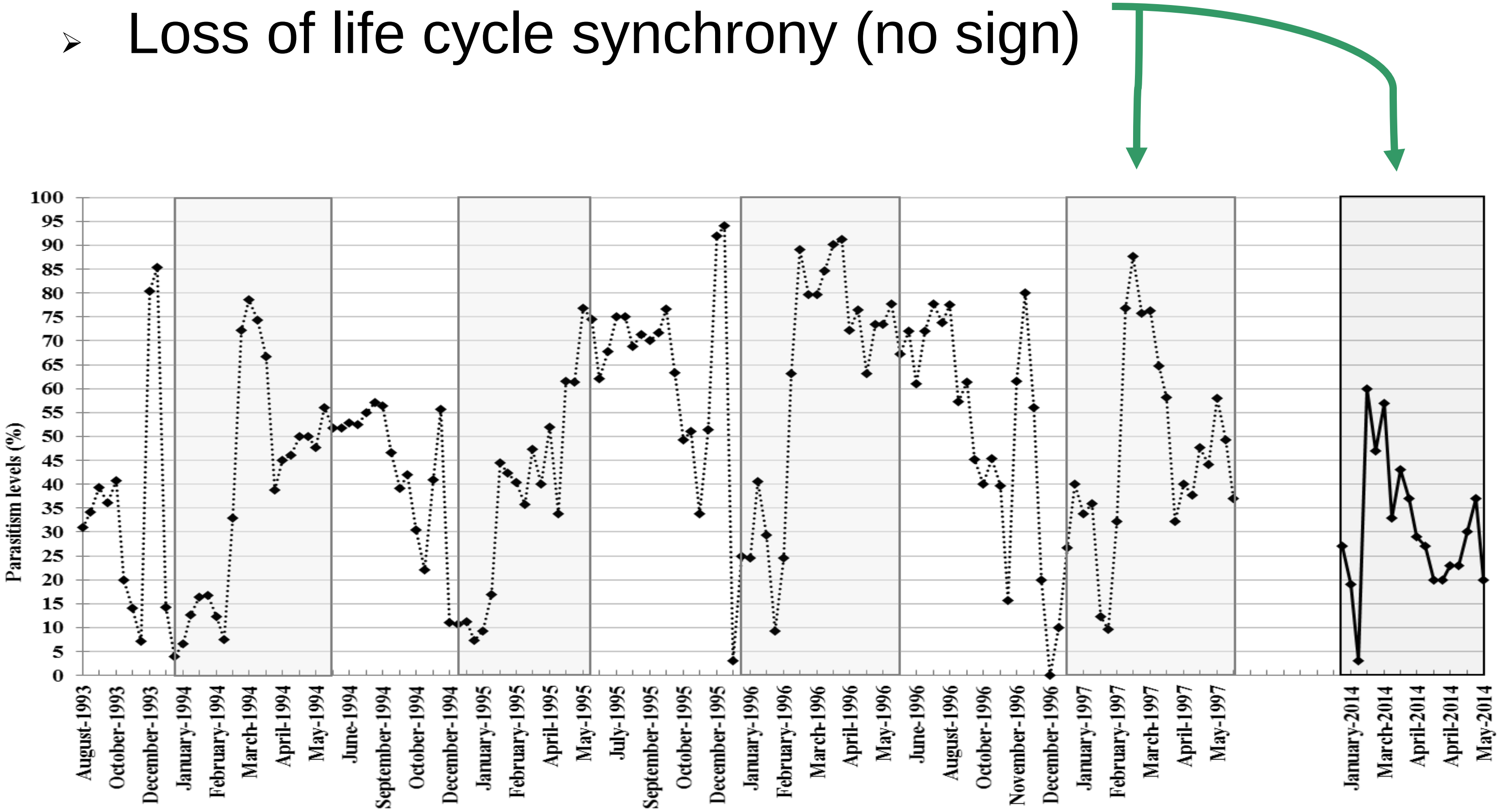
Also worrying…

Severe pest of white clover, the clover root weevil *Sitona obsoletus* also is controlled by a parthenogenetic *Microctonus aethiopoides* in precisely the same ecosystem

Could it go the same way? (Pest =$444 million p.a.)

So why has control of *ASW* by *M. hyperodae* collapsed? What it isn't… (2)

- Encapsulation (no sign)
- Loss of life cycle synchrony (no sign)



So why has control of ASW by *M. hyperodae* collapsed? (3)

Don’t know. If result of selection pressure, could be…
Genetic?

- Shift in resistant allele frequency?
- Selection for resistant mutations?
- Epigenetic plasticity?
- Pathogens and symbionts?

Approaches using historical biological material and techniques based on next generation sequencing

ASW genetic diversity little found? Interesting new observation from Chatham Islands…

So why has control of ASW by *M. hyperodae* collapsed? (4)

- Don't know; something prosaic like reaching population equilibrium. Various equilibrium models:
  - Lotka/Volterra equilibria?
  - Nicholson/Bailey equilibria?
- Theory = local extinctions of weevils followed by reinvasion lagged recoveries of parasitism
- Metapopulation effects lead to collapse

Unlikely; v high searching efficiency

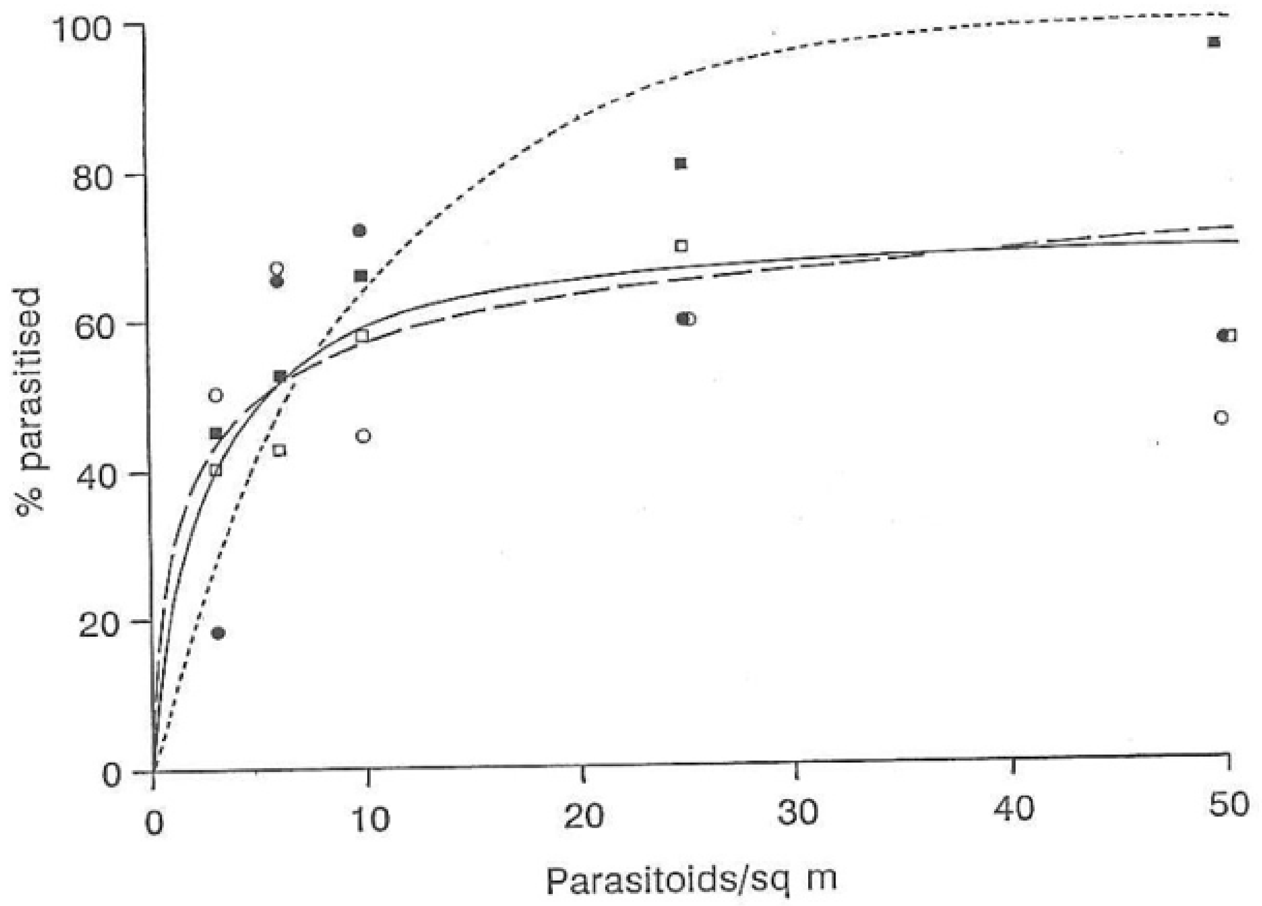
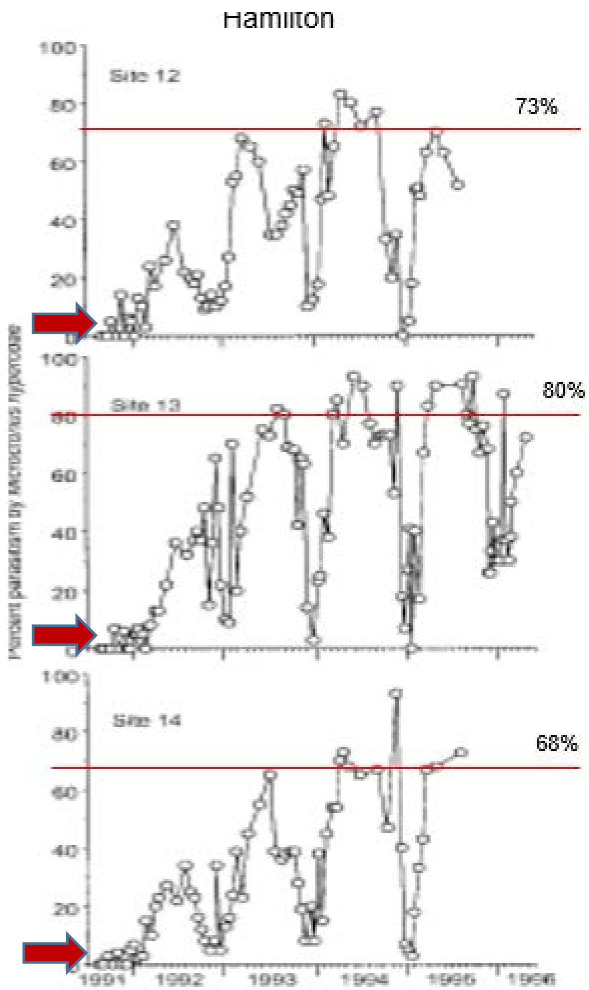


Figure 1. The relationship between % parasitism of weevils in the cages and parasitoid density. The different initial weevil densities are indicated by the different symbols for each level of parasitism (○ 25 m^{-2}, • 50 m^{-2}, □ 125 m^{-2}, ■ 200 m^{-2}). ---------- = Nicholson/Bailey model, — — — — = Models 1 and 2, ———— = model 3.

Unlikely; very rapid build up post (small) releases



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So why has control of ASW by *M. hyperodae* collapsed? (5)

- Parasitoid re-establishment rates v high; high searching efficiency
- Parasitised weevil population & parasitism v unlikely to go extinct

Thus hypothesis is unlikely; genetic work now picking up pace. Changes in allele

Conclusion

Parasitism collapse has definitely happened; Not sure why…

- NZ pastures novel; little biodiversity/biotic resistance = v high invasive pest densities
- NZ pastures novel; little biodiversity/biotic resistance = v fast pathenogenetic pest build up

Rapid success followed then followed by collapse because:

- Adaptive arms race can't happen (parthenogenesis)
- Habitat sparseness = no refugia for susceptible ASW

Thus reason for success = the seeds of its failure?

Hoisted by its own petard

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