Stress Inflicted by Organisms on Canada Thistle

S.F. Forsyth* and A.K. Watson
Department of Plant Science, Macdonald College of McGill University, 21,111 Lakeshore Road, Ste-Anne-de-Bellevue, Quebec, Canada H9X 1C0.

Abstract
The emphasis in biological weed control programs has been on weed suitability for biocontrol and host-specificity of selected organisms. Information on effects of damage caused to individual plants and on weed population dynamics has been limited. This case study with Canada thistle (Cirsium arvense) evaluated the stress inflicted by five organisms. Attack by the seed head predator, Orellia ruficauda, occurred in up to 70% of the heads and caused about 21.5% seed reduction/head and may reduce seed dispersal. Root crown damage caused by Cleonus piger sometimes resulted in plant death, but regeneration of damaged vascular tissue also occurred. A defoliation level of > 50% was required to reduce thistle vigour and Cassida rubiginosa rarely achieved this in nature. Urophora cardui gall formation on the main shoot resulted in stunted plants and reduced flowering. Plants that emerged systemically infected with the rust, Puccinia punctiformis, rarely survived the season.

Effets Perturbateurs des Organismes sur le Chardon des Champs
Dans les programmes de lutte biologique contre les plantes nuisibles, la priorité a été accordée à l'aptitude des plantes nuisibles à se soumettre à un contrôle biologique et à la spécificité d'hôtes d'organismes choisis. Les données sur les effets des perturbations causées à chaque plante et sur la dynamique des populations des plantes nuisibles sont limitées. Cette étude de cas sur le chardon des champs (Cirsium arvense) avait comme objectif d'évaluer les effets perturbateurs causés par cinq organismes. L'attaque du prédateur des têtes de graines, Orellia ruficauda a été relevée dans 70% des capitules où elle a entraîné une réduction d'environ 21.5% du nombre de graines par capitule et elle peut entraîner la dispersion des graines. Dans certains cas, la détérioration des couronnes de racines due à Cleonus piger a provoqué la mort des plantes; mais on a également observé un arrêt de la régénération des tissus vasculaires ravagés. Une défoliation de l'ordre de plus de 50% était nécessaire afin de réduire la vigueur des chardons, ce que Cassida rubiginosa a rarement pu provoquer dans la nature. Des plants rabougris et une diminution de la floraison ont été causés par la formation de galles de Urophora cardui sur la pousse principale. Les plants qui étaient systématiquement infectés par Puccinia punctiformis (rouille) au moment de leur apparition, résistaient rarement pendant la saison.

Introduction
It has been recognized in the last decade that a major constraint to biological weed control programs is lack of information on stress of target weeds resulting from attack of organisms employed (Harris 1978, 1980). For the purpose of this study, stress is defined as a measurable adaptation or response to some perturbation in the environment. A negative response could potentially result in reduction of reproductive capacity, and therefore could affect the population dynamics of the weed. Plant abundance depends

*Present address: Agriculture Canada Research Station, P.O. Box 440, Regina, Saskatchewan, Canada 6PR 3A2.
on several factors and the interactions and relationships can be very complex. Factors which can determine whether or not an agent will reduce plant populations include: climatic and edaphic conditions; intra- and inter-specific competition (both agent and weed levels); and characteristics of the biocontrol agent such as searching efficiency, rate of increase, ease of establishment, and predation (Harris 1980; Winder and van Emden 1981).

Stress should be considered as a selection criteria for biological control candidates. One proposal is to determine the type of damage caused and relate this to an effectiveness scale. This idea has merit, but there is little agreement as to what type of damage is most effective and it is likely that standards could not be developed since the stress is probably dependent on unique characteristics of the agent and the target weed. Harris (1980) proposed several possible techniques to increase stress including: (a) decrease the mortality of the agent; (b) increase the fecundity of the agent; (c) increase the number of agent species on any target weed; (d) alter cultural practices to stress weed while still favouring the agent; and (e) select agents that inflict a high stress load.

Perhaps future biological control programs would benefit from a procedure based on a variation on a theme from Greek mythology as follows: (1) Know the plant — understand the population dynamics, habitats, growth habits, vulnerable parts of the life cycle, and so forth, of the target weed; (2) Know the agent — understand the phenology of the agent relative to the plant, the number of generations, level of field attack; and (3) integrate this knowledge of host and agent and determine the level of stress caused by the organisms and relate this to a stress threshold arrived at through simulation or modelling techniques using the population dynamics of the host.

Most of the work in biocontrol is directed towards vigorous and troublesome perennial weeds and the emphasis of herbivory is centered on annual production of seed or biomass rather than the often more important vegetative propagation from root buds or rhizomes. These asexual propagation methods of perennial weeds present a more complex control problem than for an annual weed or a biennial weed. Vegetative propagation also increases the complexity of studying stress effects and population dynamics of the perennial weeds.

A case study involving the stress caused by five natural enemies on Canada thistle (Cirsium arvense [L.] Scop.; Compositae) will be discussed (Forsyth 1984). The natural enemies include: Oreillia ruficuda (F.) (Diptera: Tephritidae), a seed feeder; Cleonus piger Scop. (Coleoptera: Curculionidae), a root crown inhabitant; Cassida rubiginosa Müller (Coleoptera: Chrysomelidae), a defoliator; Urophora cardui (L.) (Diptera: Tephritidae), a stem gall causer; and Puccinia punctiformis (Str.) Rohl (Uredinales), a systemic rust.

In this discussion, the following points of stress physiology will be addressed:

1. Importance of feeding loci for biocontrol of perennials:
   (a) seed predator (loss of reproductive capacity — seed);
   (b) root crown inhabitant (blockage or damage to translocation elements);
   (c) defoliator (loss of photosynthetic area);
   (d) gall formation (alteration of resource partitioning); and
   (e) systemic rust growth (disease);

2. Plant phenological stage of attack;

3. Density of natural enemies/amount of damage;

4. Length or repetitiveness of attack; and

5. Combination of stresses.
Materials and Methods

These studies were performed from 1980–83 at Macdonald College of McGill University, Ste.-Anne-de-Bellevue, Quebec, Canada. Field studies were done on the five natural enemies at four field sites on the College property. Physical damage caused by the agents was qualitatively assessed by light microscopy. Quantitative data on stress was gathered for gall formation, after rust inoculations with urediniospores, for insect and simulation defoliation and simulation of root crown damage. Parameters recorded included height, dry weight, root, bud and ramet production, among others. Additional physiological measures including sugar and protein content of various tissues, radioactive tracer experiments and others were also performed. Manuscripts on the stress physiology caused by each of these organisms are in preparation for publication elsewhere.

Results and Discussion

Feeding Loci

Seed predation. *O. ruficauda* attacked up to 70% of seed heads and destroyed 0–90% of the seeds/head. The effect of this predispersal seed predator is probably minimal in reducing populations of established stands in pastures and rangelands where Canada thistle seedling survival is low. Seed predation is not as important in reducing a perennial weed population with alternate means of propagation as it is to an annual plant where seed production is the only means of propagation. However, if a seed predator does reduce the seed production of a perennial weed, it can potentially reduce the dispersal and thereby possibly decrease infiltration of arable land and minimize new stands initiated from seedling growth.

Root crown inhabitant. *C. piper* larvae caused a rudimentary gall to be formed in the root crown region of Canada thistle. Up to 27% of sampled plants contained *C. piper* larvae in Quebec, Canada, with wilting the field symptom of *C. piper* inhabitation. Microscopical examination indicated that *C. piper* causes wilt by damage to the xylem tissue. However, tissue regeneration occurred and only occasionally did attacked plants die. Plant death occurred primarily on poor soils. More commonly, attacked plants were not adversely affected, with flowering time and flower number not significantly reduced. The weevil tended to choose larger plants (due most likely to its large size). The effect of *C. piper* on ramet or root bud production is not known.

Defoliation. In the field, *C. rubiginosa* caused minimal damage to Canada thistle plants, and as with *C. piper*, seemed to be attracted to larger plants. Simulation experiments indicated that maximum stress occurred on young plants when the defoliation level was high (50% leaf removal or more). High levels of defoliation can significantly reduce height, flower number, sideshoot number and dry weights of the defoliated plant, root and total dry weight, and most importantly for future control, a reduction of root bud and ramet production.

Gall formation. *U. cardui*, an insect imported into North America in the classical biological control program for Canada thistle, induces stem gall formation on the sideshoots and/or mainshoot of Canada thistle plants. For current year production of biomass, mainshoot galls are much more detrimental to the plant than sideshoot gall development, resulting in lower heights and reduced and delayed flowering. Gall formation can also significantly reduce root dry weight and ramet number. Radioactive tracer studies indicated that the gall was a weak physiological sink when it was forming,
but not when mature. Sidestalk galls appeared to have less effect than mainstalk galls on current year production, but effect on root bud production is not known. Most of the work presented was conducted under controlled environmental conditions and the effect in nature could be either less detrimental, due to a more advanced and complex root system with greater resource storing capabilities, or more detrimental due to additional environmental stresses, such as other natural enemies and competition from other plants.

Systemic rust formation. *P. punctiformis* can significantly stress Canada thistle (Watson and Keogh 1981). Systemically infected shoots rarely survive the season, but the naturally occurring field level is low and rarely eliminates a Canada thistle population. As early as 1915, Cockayne (1915) recommended that infection with this rust must be increased beyond naturally occurring levels to be an effective means of control. Some progress was made on the examination of the infection process. Under controlled environmental conditions, it was found that as number of leaves infected by inoculation with urediniospores increased, proportion of systemic infection increased. With multiple inoculations, more frequent inoculations resulted in earlier, greater number and greater frequency of production of systemically infected ramets. Some preliminary tissue culture work indicated that systemically infected callus could be prepared.

Summary. There appears to be no magical place to attack a perennial weed. Consideration of the type of attack should not become a prerequisite for agent selection, but rather the damage should result in a reduction of reproductive capabilities. Actual damage (type and/or amount) is not important, but stress on root bud and seed production is important. No firm conclusions as to which type of damage would be most effective can be stated from this study. The efficacy of a seed head predator seems relatively low for Canada thistle. It seems reasonable to assume that an additional seed head predator in eastern Canada would not be an asset. However, in western Canada, where Canada thistle is a problem in cultivated fields, additional seed feeding may be appropriate. Some predation by *Rhinocyllus conicus* Froelich (Coleoptera: Curculionidae), a biocontrol agent released on *Carduus nutans* L. (Compositae) does occur, but the effectiveness on Canada thistle is not known.

Damage to vascular tissue seemed to be effective if the root system was already under stress; the only field plants that died from *C. piger* attack occurred on very poor soil. The tremendous regenerative capacity of the vascular system counteracts the damage and probably also the disorganization caused by gall formation.

*U. cardui* gall formation resulted in only a low level of stress to the plant. *U. cardui* galls are weak sinks. This, however, does not preclude all gall inducers which may be more efficient at assimilate repartitioning during their formation. If a gall were a good sink, then it could draw resources from the roots and thereby reduce vegetative propagation.

For perennials, defoliators must remove a substantial amount of foliage to have a detrimental effect. Leaf regrowth capacities are substantial and only defoliation levels of greater than 50% resulted in any significant damage.

The systemic rust was the most effective natural enemy in this study. Further studies for the determination of techniques needed to cause an epidemic of this pathogen should be initiated.

**Phenology Stage of Weed at time of Attack**

There have been suggestions that an effective perturbation should occur when the carbohydrate level is low. For gall formation, and in defoliation simulation experiments,
stress on regenerative factors (root weight, root bud number) was greater for young plants (Table 1). For biocontrol of perennial weeds, it may be more effective to attack younger plants to decrease initiation of root bud primordia rather than delaying until later in the season when root buds are already formed. Both *U. cardui* and *C. rubiginosa* attack plants during early bud to flowering stages and are therefore poorly synchronized with their host plant in inflicting damage. A practice such as early mowing or sheep grazing could stunt plant development to allow for better synchrony of these two organisms and possibly greater stress. The rust illustrates the effectiveness of early attack on the weed; each plant that emerges in the spring infected with the rust usually dies.

**Density of Natural Enemy or Degree of Damage**

It seems reasonable to assume that the greater the damage (or the higher the number of the natural enemy), the more detrimental the effect on the plant. This assumption was confirmed by this study with both the gall inducer and defoliation simulation. Gall size was positively correlated with larval number, and it has been postulated that stress on the plant should increase with larvae number. Evidence of this was indicated in Table 2. Higher levels of defoliation resulted in greater stress on plants (Table 3). The threshold concept of biological control assumes that a damage level can be achieved above the threshold and result in plant population reductions. However, no proof that the carrying capacity of the agents will correlate with the threshold level is manifest; this remains to be tested.

<table>
<thead>
<tr>
<th>Age (cm)</th>
<th>Height (cm)</th>
<th>Ramet no.</th>
<th>Flower no.</th>
<th>Root bud no.</th>
<th>Dry weight (g) Plant</th>
<th>Root</th>
</tr>
</thead>
<tbody>
<tr>
<td>S</td>
<td>R</td>
<td>S</td>
<td>R</td>
<td>S</td>
<td>R</td>
<td>S</td>
</tr>
<tr>
<td>5</td>
<td>59.9a 39.9b</td>
<td>9.4</td>
<td>6.4c</td>
<td>4.4</td>
<td>0.8b</td>
<td>12.3</td>
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<tr>
<td>10</td>
<td>56.8ab 40.6b</td>
<td>11.5</td>
<td>7.4bc</td>
<td>3.5</td>
<td>1.1b</td>
<td>14.6</td>
</tr>
<tr>
<td>15</td>
<td>52.8b 45.2ab</td>
<td>10.1</td>
<td>9.5ab</td>
<td>3.6</td>
<td>1.3b</td>
<td>13.0</td>
</tr>
<tr>
<td>20</td>
<td>51.8b 50.8a</td>
<td>8.0</td>
<td>10.4a</td>
<td>4.1</td>
<td>2.3a</td>
<td>9.9</td>
</tr>
</tbody>
</table>

1Averaged over five defoliation levels: 0, 25, 50, 75 and 100% of leaves removed.
2Age in leaf number at first treatment.
3Treatments: S = single defoliation; R = repeated defoliation.
4Means with the same letter in the same column are not significantly different. Means with no letters are not significantly different. (Duncan's multiple range test, P < 0.05.)

**Length and/or Repetitiveness of Attack**

The longer the plant is under stress, the greater will be the detrimental effects. Also, if the duration is short, then repetition of perturbation could be more detrimental than a single one (Winder and van Emden 1981). This was found for defoliation simulation in this study (Tables 1 and 3). The repeated defoliation treatment generally resulted in lower vigour than a single defoliation. This factor is complexed by the time of initiation of herbivory or times of repeated attack, length of time between attacks (time for compensatory growth), number of attacks, or length of a single long attack. Repeated inoculations with *P. punctiformis* also resulted in a greater production of systemically infected ramets.
Combinations

Although spectacular success in biological control has been achieved with only one agent/weed (for example, Cactoblastis cactorum Berg [Lepidoptera: Pyralidae] moth on prickly pears, Chrysomela spp. [Coleoptera: Chrysomelidae] beetles on St. John's wort and R. conicus on nodding thistle), these cases are exceptional. Most weeds probably require three or more natural enemies to achieve control. A mathematical model based on the Leslie matrix model, used to test effects of various natural enemies, indicated that separately the organisms did not reduce the weed, but in combination, the effect was much greater. Without these natural enemies, Canada thistle could be a greater problem than it is at present; indeed in the western Canadian provinces where C. rubiginosa and C. piper do not occur and P. punctiformis is rare, Canada thistle is a greater problem. This indicates that the stress resulting from attack by these organisms, though minor, is probably affecting Canada thistle population dynamics.

Table 2. Effect of gall size on growth and reproductive parameters of Canada thistle (Cirsium arvense L.).

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Gall size</th>
<th>LSD (0.05)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Small</td>
<td>Medium</td>
</tr>
<tr>
<td>Height (cm)</td>
<td>36.5</td>
<td>28.9</td>
</tr>
<tr>
<td>Root bud number</td>
<td>28.0</td>
<td>19.6</td>
</tr>
<tr>
<td>Fresh weight (g)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Plant²</td>
<td>34.8</td>
<td>25.9</td>
</tr>
<tr>
<td>Root</td>
<td>19.3</td>
<td>11.7</td>
</tr>
<tr>
<td>Dry weight (g)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Plant²</td>
<td>6.8</td>
<td>5.6</td>
</tr>
<tr>
<td>Root</td>
<td>4.2</td>
<td>2.8</td>
</tr>
</tbody>
</table>

¹Size: small, < 5 cm²; medium, 6–8.5 cm²; and large, > 8.5 cm².
²Weight of remaining stem and leaves after gall removal.

Conclusions

Interactions of natural enemies and plant populations are complex and studies should become a part of the biological control program protocol and could eliminate further study on agents which either: (a) are inappropriately synchronized with the host plant phenology to cause significant damage; (b) do not cause a relatively high level of damage; or (c) cause damage to plant loci which are highly resistant to damage. These comments do not suggest that only those organisms that cause massive damage be considered, since each one no matter how small adds to the stress of the plant, but that more astute selections may be made. An understanding of the stress levels that each agent inflicts on the plant relative to known threshold stress levels, which can result in population decline would be the ideal situation, a concept which is being examined at present. This would allow prediction of the number of insects and pathogens required to obtain control. This study has shown that for perennial weeds, the most detrimental type of damage appears to be a virulent pathogen, which results in demise of each plant it infects, in root damage, and ultimately in reduction of vegetative propagation. Defoliation, if heavy and repetitive would be damaging, since it draws resource from the root and flowers for the replacement of the leaf material lost. Gall inducers, rated by Harris (1973) as causing low damage, do seem to have less detrimental
effect, since as Shorthouse (pers. comm.) states, gall insects live ‘off the interest’, not ‘off the capital’.

Little can be done to alter insect development rates to match the susceptible stage of the weed, but management practices to delay weed growth can be utilized. Appropriate timing of damage may be as important as massive damage.

This type of information may be important for the development of biocontrol programs and may provide more accurate prediction for agent selection. The tremendous regenerative capacity and vigour of perennial weeds makes them effective weeds and difficult to control. Many interacting factors act together to regulate the population dynamics of the weed. This study has begun the investigation of a relatively unknown area, the effect of the natural enemies on the weed. Present similar studies on another perennial weed problem, leafy spurge (Euphorbia esula L.; Euphorbiaceae) are in progress.

Table 3. Effect of defoliation level\(^1\) on plant growth and reproductive parameters.

<table>
<thead>
<tr>
<th>Defoliation percentage</th>
<th>Height (cm)</th>
<th>Ramet number</th>
<th>Flower number</th>
<th>Root bud number</th>
<th>Dry weight (g)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>S(^2)</td>
<td>R(^2)</td>
<td>S(^3)</td>
<td>R(^3)</td>
<td>Plant</td>
</tr>
<tr>
<td></td>
<td>Root</td>
<td>Root</td>
<td>Root</td>
<td></td>
<td>Root</td>
</tr>
<tr>
<td>0</td>
<td>60.1a</td>
<td>58.3a</td>
<td>11.2</td>
<td>11.7a</td>
<td>6.4a</td>
</tr>
<tr>
<td>25</td>
<td>51.7b</td>
<td>54.2a</td>
<td>10.0</td>
<td>9.4a</td>
<td>4.9a</td>
</tr>
<tr>
<td>50</td>
<td>58.4a</td>
<td>45.8b</td>
<td>8.6</td>
<td>9.9a</td>
<td>4.6ab</td>
</tr>
<tr>
<td>75</td>
<td>49.4c</td>
<td>31.9c</td>
<td>11.0</td>
<td>6.2b</td>
<td>1.7b</td>
</tr>
<tr>
<td>100</td>
<td>56.8ab</td>
<td>27.1c</td>
<td>8.0</td>
<td>4.8b</td>
<td>1.9b</td>
</tr>
</tbody>
</table>

\(^1\) Averaged over four ages: 5, 10, 15, and 20 leaf stages.
\(^2\) Treatments: S = single defoliation; R = repeated defoliation.
\(^3\) Means with the same letter in the same column are not significantly different. Means with no letter are not significantly different. (Duncan’s multiple range test; \(P < 0.05\)).

Acknowledgments

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References