Population size estimation for the Warren root collar weevil, *Hylobius warreni* Wood (Coleoptera: Curculionidae), a pest of regenerating lodgepole pine plantations

S. L. BALOGH[1], N. BJÖRKLUND[2], D. P. W. HUBER[1], AND B. S. LINDGREN[1]

ABSTRACT

The Warren root collar weevil, *Hylobius warreni* Wood (Coleoptera: Curculionidae), is an endemic pest species of conifers, particularly lodgepole pine (*Pinus contorta* var. *latifolia*) (Pinaceae), in British Columbia. Larvae feed on the roots and root collars of young trees, resulting in girdling damage and mortality or growth reductions. Population sizes of adult *H. warreni* have historically been difficult to assess due to a lack of operational sampling methods or chemical attractants for the species. Therefore, most previous population estimates have relied on indirect or incomplete measures of damage by immature individuals. In this study, we tested the Björklund funnel trap to assess its efficacy as a method to estimate *H. warreni* populations. Funnel traps were placed on all 182 trees in half of a small (~1 ha) lodgepole pine stand over four days and remained in place for 13 days after the last traps were installed. Adult weevils were captured, marked, and released on the bole of the tree on which they had been caught. It is likely that most of the adult weevils in the plot, which was isolated from any nearby lodgepole pine stands, were caught at least once and many were caught multiple times. Population sizes were estimated using both the Schnabel method and the Schumacher and Eschmeyer method, resulting in population estimates of 1.83-2.19 weevils/tree and 731-875 weevils/ha. These measures are within the range of population sizes estimated by previous studies. The results suggest the Björklund funnel trap may be an effective operational tool for population monitoring for this species and may also be an effective tactic in population reduction strategies.

INTRODUCTION

The Warren root collar weevil, *Hylobius warreni* Wood (Coleoptera: Curculionidae), is endemic to British Columbia and other regions throughout most of Canada. It is a large (12–15 mm long), long-lived (up to five years as an adult) weevil common in lodgepole pine forests in British Columbia. It is flightless, with fused elytra, and generally only moves about a few metres per day, corresponding to the host-tree spacing (Cerezke 1994; Machial *et al.* 2012a; Balogh *et al.* 2020). Adult weevils ascend trees at night, where they feed on bark, although this adult feeding typically results in minimal damage (Cerezek 1994).

[1]Natural Resources and Environmental Studies Institute, University of Northern British Columbia, 3333 University Way, Prince George, BC V2N 4Z9; sharleen.balogh@alumni.unbc.ca
[2]Department of Ecology, Swedish University of Agricultural Sciences, P.O. Box 7070, SE-750 07, Uppsala, Sweden

However, larvae of the species feed on the roots of young conifers, particularly lodgepole pine, *Pinus contorta* var. *latifolia* Douglas ex Loudon (Pinaceae). This larval feeding can cause girdling damage, resulting in mortality and growth reductions in small and large trees, respectively (Warren 1956; Cerezke 1972, 1974, 1994; Schroff *et al.* 2006), which has an important impact on forest ecosystems because it influences regeneration (Cerezke 1994). The weevil is also an emerging pest in some of Canada's plantation forests in the wake of massive insect- and fire-based disturbances and subsequent replanting of Canadian forests in recent years (Cerezke 1994; Klingenberg *et al.* 2010a; Robert and Lindgren 2010). Because of this, an understanding of *H. warreni*'s foraging decisions and populations has become increasingly important. Knowledge of population sizes or abundance is often central to many ecological studies (Krebs 1999) and is a vital metric in pest management strategies. For example, the establishment of economic thresholds of pest populations requires accurate estimation of population sizes (Rieske and Raffa 1990).

Hylobius warreni population sizes have been historically difficult to assess due to a lack of simple sampling methods (Warren 1956; Cerezke 1994). In addition, attractant-based trapping techniques that are commonly used with other weevil species have not been successful with this pest because of the apparent lack of chemical attractants for *H. warreni* (B.S. Lindgren, unpublished data). As a result, previous work on *H. warreni* population sizes and densities has typically relied on indirect or incomplete indicators and has predominately focussed on measuring the number of immature individuals. For example, Warren's (1956) Damage Index is based on the average percentage of girdling from larval feeding scars per tree and Cerezke's (1970a) method linearly relates the number of current attacks to the number of immature individuals per tree. The development of an effective nonchemical trap (Björklund 2009) has greatly enhanced the ability to monitor *H. warreni,* making it a useful insect for dispersal and host -selection studies (*e.g.,* Machial *et al.* 2012a,b; Balogh *et al.* 2020). Our objectives for this study were to develop a method for directly estimating populations of adult individuals in the field using capture–mark–recapture and to use the method to give the first direct estimate of a population of this insect in a young lodgepole pine stand.

METHODS

This study re-analyses data that were collected during the design and testing of the Björklund funnel trap (Björklund 2009) and that were previously published with different analyses in Klingenberg *et al*. (2010b) and Balogh *et al.* (2020) for the new purpose of assessing the trap as a method of population estimation. These previously published data showed that the number of weevils captured by traps in this stand was higher when traps were placed on larger-diameter trees and lower on trees in poor health; the data also showed that capture frequencies of the traps were influenced by the spatial characteristics of the trees in the stand (Balogh *et al.* 2020).

The study area consisted of half of a small (~1 ha) site that comprised young planted lodgepole pines regenerating in an urban green space in Prince George, British Columbia (53° 55′ N, 122° 49′ W), approximately 0.455 ha in size. For additional details on the characteristics of the study area, see Klingenberg *et al.*

(2010b) and Balogh *et al.* (2020). The site was bordered on three sides by deciduous forest and on the fourth side by a roadway. Monitoring of young pines on the other side of the road did not reveal the presence of any weevils, and we are confident that migration into and out of our study stand was minimal. Weevils were trapped in Björklund funnel traps (Björklund 2009) affixed to the lower boles of all 182 trees in the study area. The first 100 traps were installed on 26 May 2006, 18 traps were installed on 27 May 2006, 13 on 28 May 2006, and 51 traps on 29 May 2006. The traps remained in place for 13 days following installation of the final traps.

Briefly, a Björklund funnel trap consists of an outer side of asphalt-saturated kraft paper (Vaporex 400S, Building Products of Canada Corporation, LaSalle, Québec, Canada) and an inner side covered in Fluon® (AD1070, AGC Chemicals Americas, Inc., Bayonne, New Jersey, United States of America), a fluoropolymer resin that is slippery to most insects, wrapped once around the lower bole of a tree in a funnel configuration. Adult beetles can climb the outer portion of the funnel while attempting to scale the bole to feed in foliage but falls into and remains entrapped by the slippery inner portion. See Klingenberg *et al.* (2010b), Fig. 1 for a photograph of the trap.

We collected captured weevils each morning for the duration of the entire study period, from the installation of the first traps on 26 May to the end of the study on 11 June. Weevils captured for the first time were marked with Liquid Paper correction fluid (Paper Mate, Oak Brook, Illinois, United States of America) and a unique alphanumeric designator, and the designations were recorded if they were captured on subsequent mornings. All captured weevils were then immediately returned to the bole of the tree on which they had been caught.

We estimated the population size and density of adult individuals in the lodgepole pine stand using both the Schnabel method and the Schumacher and Eschmeyer method (Krebs 1999). Only weevil captures after all traps were in place were used in the population-size calculations. There are several basic assumptions of population estimators that rely on capture–mark–recapture techniques, including that the population is a closed population, that sampling is random, that all individuals are equally catchable (Krebs 1999), and that capture frequencies remain stable over the time of the study (Rieske and Raffa 1990).

Previous work on this data set had determined, by a graphical representation of the number of trees with captured weevils over time, that the capture efficiencies of the traps did not decline over the time of the study (Klingenberg *et al.* 2010b, Figure 4). To further test this assumption, we used a linear regression model to compare the total number of captures on a given night over time (number of days since all traps were in place, beginning with day 1 on 30 May 2006). The regression showed no significant relationship between the number of captures and time (R^2 = 0.03, $F_{(1,11)}$ = 0.30, P = 0.60; Figure 1). Both of these measures suggest that the capture efficiencies of the traps remained constant throughout the study period and that the handling and marking of the weevils likely had a minimal effect on the likelihood of their future capture. We considered the assumption of a closed population to be satisfied in this study, due to the geographical and biological features of the stand. We were not able to directly test the assumption of random sampling, because there was no indication if there were adult individuals in the population that did not ascend trees at all.

Krebs (1999) suggests that the overall assumptions of capture–mark–recapture population estimation methods can be evaluated by a plot of the total number of marked individuals *versus* the proportion of the weevils captured each day that are recaptures. In the present study, this plot showed a linear relationship (Fig. 2), indicating that the basic assumptions of population estimation methods were adequately met (Krebs 1999). We calculated 95% confidence intervals for the Schnabel method by a normal approximation and for the Schumacher and Eschmeyer method from the variance of the linear regression (Krebs 1999). Both population intensity (weevils per tree) and absolute population numbers (weevils per hectare) were calculated as per Cerezke (1994), whereas population estimates and confidence intervals were calculated using the formulas on pages 35–39 of Krebs (1999). The full dataset used in the population estimates is publicly available at https://doi.org/10.6084/m9.figshare.14171258.v1.

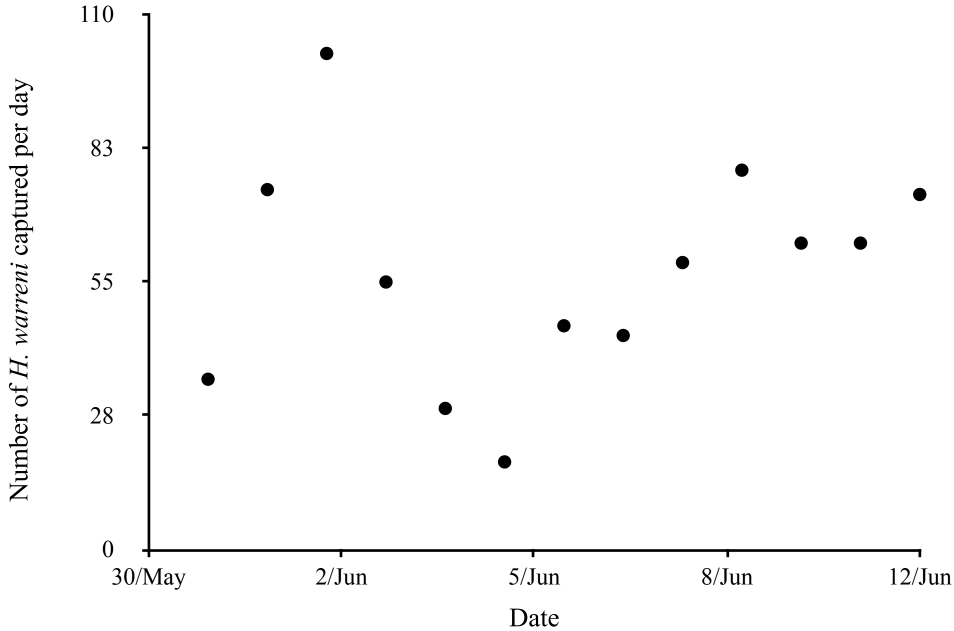

Figure 1. Number of individuals of *Hylobius warreni* captured per day over a 13-day period in 2006 in a capture–mark–recapture study of *H. warreni*. The regression line was not statistically significant, indicating that capture rates remained constant over time.

RESULTS

A total of 341 unique individuals were captured over the entire study period, with many weevils captured multiple times (Figure 3). The estimated population size estimate obtained from the Schnabel method was 363 (95% confidence interval = 333–398) weevils, whereas the population size estimated from the Schumacher and Eschmeyer method was 345 (95% confidence interval = 336–355) weevils. The 95% confidence intervals from both methods therefore contain the actual number of captured and marked weevils and suggest that the population size is within the range of 333–398 weevils. Weevil populations were therefore estimated between 1.83–2.19 weevils per tree and absolute population estimates ranged between 731–875 weevils per hectare.

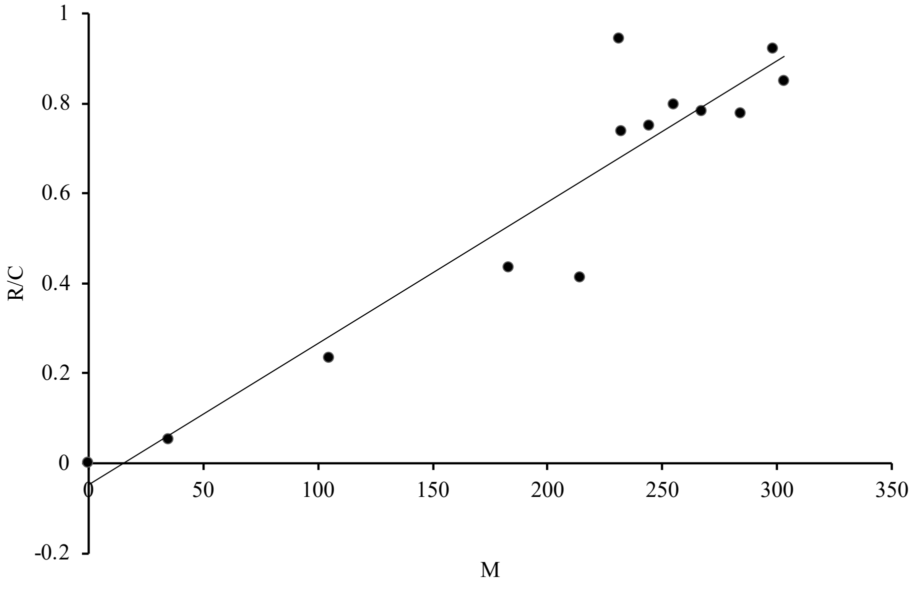

Figure 2. Linear relationship between the total number of marked individuals (M) and the proportion of the individuals captured each day (C) that were recaptures (R) in a capture–mark–recapture study of *Hylobius warreni*.

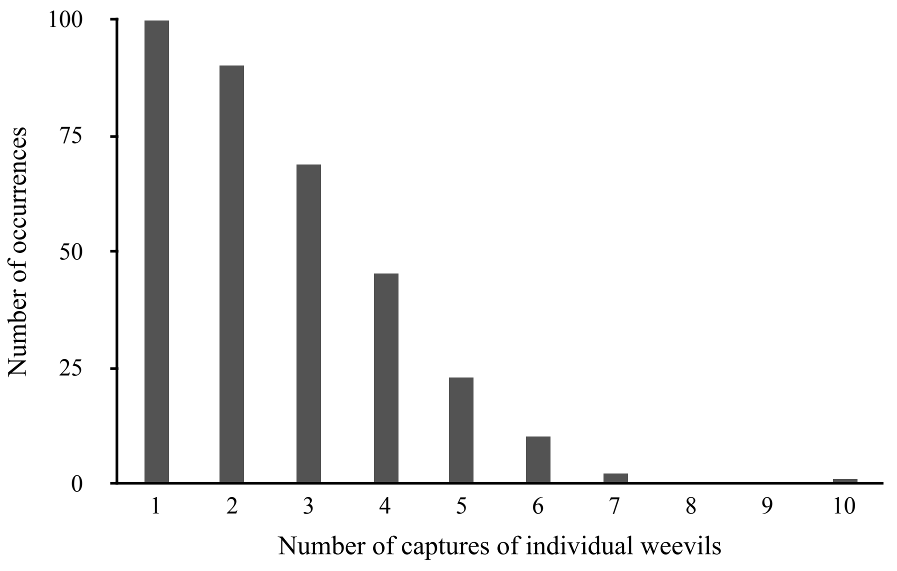

Figure 3. Histogram showing the total number of times individual weevils were captured by Björklund funnel traps in a capture–mark–recapture study of *Hylobius warreni*.

DISCUSSION

To our knowledge, our study is the first to directly estimate the population of adult individuals of *H. warreni* in a stand, rather than basing estimates of populations on immature life stages or indirect measures such as damage. For example, Cerezke (1994) found immatures in a variety of lodgepole pine stands ranging between 215 and 2760 weevils per hectare and 0.047 and 4.26 weevils per tree. Cerezke (1970b) also provided indirect estimates of population densities in various stands by linearly relating the number of feeding scars to the number of weevils per tree. Where weevils were present at all, their abundance ranged from 21 to 631 weevils per acre (52 to 1559 weevils per hectare). The population densities estimated in our study (731–875 weevils per hectare) are within the ranges that have been estimated previously for immature individuals and suggest that adult individuals form a substantial portion of the total weevil population. In addition, the range of densities estimated and the observation that the capture rates of the traps did not decline with time support the hypothesis that the trapping method can be effectively used to estimate *H. warreni* populations.

The traps appear to have captured the majority of the adult individual *H. warreni* in the stand at least once, suggesting that this method is highly efficient. Björklund funnel traps are useful for monitoring *H. warreni* populations and may potentially be used as a pest management tactic in some contexts to capture most of the adult beetles in a plantation. Monitoring adults provides a better indicator of long-term population trends than monitoring immature stages does, because the adult stage lasts longer in *H. warreni* and therefore would show less year-to-year variation. In addition, trap-based removal of a high proportion of the adults from lodgepole pine plantations can be expected to dramatically reduce damage to young trees by reducing larval production.

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