

The Response of Swamp Harebell (*Campanula californica*) to Timber Harvest: a Case Study¹

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Abstract

A perennial herb of the Campanulaceae (bellflower) family, swamp harebell (*Campanula californica*) is endemic to the north and central coast of California. The California Department of Fish and Wildlife (CDFW) considers the species to be moderately threatened, and is concerned with the severity of impacts from land use activities, and the effectiveness of mitigation measures proposed under California Environmental Quality Act compliance. A timber harvesting plan (THP) submitted during 2000 reported the species distributed in several clusters in the proposed Sonoma County logging area. During review, CDFW and the landowner agreed to evaluate the impacts of some standard timber harvest practices. Following a repeated-measures design with sampling the year prior to harvest and post-harvest years 1, 3, and 5, we enumerated swamp harebell plants in five 30 cm x 30 cm subplots systematically placed within twenty 3 m x 1 m cover-class quadrants. We situated the cover-class quadrants to assess four immediate on-site impacts: road reopening/hauling, timber falling and skidding, reducing canopy, and minimal direct impact. The number of plants on roadways declined substantially in the first year post harvest, and remained low in subsequent years. Likewise, the number of plants declined between pre-harvest and post-harvest year 1 where trees were felled and skidded, but some recovery was apparent by the final year. Reduced canopy plots did not show substantive response attributable to harvest. Of the un-impacted sites, one declined continually and substantially (to 2 percent of its original count) over study period, while the others also generally declined. Drought conditions during the monitoring period likely impacted swamp harebell numbers more than many impacts of timber harvest, other than those resulting from road construction and use.

Keywords: *Campanula californica*, drought, roads, swamp harebell, timber harvest impacts

Introduction

Timber harvest practices alter canopy, microclimate (especially temperature and humidity regimes), hydrology, and soil conditions. The associated changes in landscapes and habitats effect different plant species in different ways. Early-successional species or hardy generalists may benefit from logging-related changes, while specialists or late-successional species may be negatively impacted. Some species may experience a “mixed-bag” of effects from harvest practices. For instance, a plant species may benefit from increased solar input resulting from canopy reduction, while being negatively impacted by drying or increased competition from non-native species introduced through ground disturbance or erosion control efforts. The effects of timber harvest practices have been well studied for few plant species. For an exception, see Renner et al. 2011. Impacts to many forest-dwelling plant species remain undocumented. For example, we know of no rigorous assessment of the response of swamp harebell (*Campanula californica*) to forestry practices.

Swamp harebell is a rhizomatous perennial herb in the bellflower family (Campanulaceae). The California Native Plant Society (CNPS) (Anonymous 2016a) and the California Department of Fish and Wildlife (CDFW) (Anonymous 2016b) categorize the species as rare, threatened or endangered in

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California and elsewhere, fairly endangered in California (1B.2) and assign the degree of threat as moderate due to either 20 to 80 percent occurrences being threatened or a moderate immediacy of threat. Currently, neither the state nor federal governments list it under their respective endangered species acts. The range of *C. californica* is limited to coastal areas in Sonoma, Marin and Mendocino counties, and CNPS (Anonymous 2016a) considers it extirpated from Santa Cruz County. Swamp harebell has slender clamoring stems 10 to 30 cm long with stiff recurved hairs and thin, opposite ovate leaves. Pale blue, bell-shaped flowers may appear from June through October. Habitats for *C. californica* include bogs and fens, closed-cone coniferous forests, coastal prairie, meadows and seeps, marshes and swamps (freshwater), North Coast coniferous forest/ mesic, at elevations less than 500 m. The CNPS (Anonymous 2016) asserts threats to be competition, grazing, development, marsh habitat loss, logging, road maintenance, and trampling.

Due to limited distribution and number of plants as well as lack of knowledge regarding its response to disturbance, this small and shallowly-rooted herbaceous plant may require some form of protection from disturbance during land management activities. Based on limited observations, some forestry professionals suggest *C. californica* benefits from disturbance caused by logging practices. These claims have not been evaluated rigorously. In the absence of supporting information, the common practice for resource professionals is to avoid or minimize impacts to *C. californica* found in harvest areas. For some projects, avoidance is not always possible.

During 2000, Registered Professional Forester (RPF) Nicholas Kent submitted timber harvesting plan (THP) 1-00-321 SON for Mr. D.M. Richardson, a non-industrial private landowner. The THP reported the discovery of swamp harebell in several clusters over part of the plan area. During the review process for the plan, the landowner and forester agreed to monitor the impacts of the timber harvest on *C. californica* populations. The CDFW took the lead role in designing and implementing this effort. Because of the study's sites treatments were not randomly assigned and are not completely independent due to the THP's limited geographic area, single time-frame, and proximity of the clusters, as well as small sample size within treatments, and the limited silviculture and harvest intensity, we consider this monitoring effort a case study.

Methods

The THP was located near Horseshoe Cove in northwestern Sonoma County, approximately 0.25 km to 1.6 km from the Pacific Ocean, and 5.6 km south of the town of Stewart's Point in Sonoma County. The plan called for Selection and Alternative Prescription silviculture harvest in a coast redwood (*Sequoia sempervirens* (D. Don) Endl.), Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco), and Bishop Pine (*Pinus muricata* D. Don) forest mosaic. The RPF surveyed the THP area for swamp harebell in July of 2002, and provided a map to CDFW. In June of 2003, prior to harvesting operations, we examined the THP area and identified 20 clusters of swamp harebell to be monitored. The clusters of *C. californica* we selected ranged from 0.3 to 0.6 km from the ocean, 60 to 120 m elevation, and were expected to experience a range of timber operations. We chose to evaluate the impacts of the plan as proposed and did not specify operational constraints be applied to any of the *C. californica* clusters; however, two clusters were within non-operational locations.

Based on THP tree marking and flagging, we assigned clusters to three different common timber harvesting related activities based on their potential effects on swamp harebell (table 1). These treatments were: road reconstruction and use, canopy (shade) reduction, and tree falling and log skidding. Clusters where timber operations were not anticipated immediately on site based on the absence of flagging or trees with harvest marks were identified as "controls". All clusters selected for study were occupied by healthy colonies of *C. californica* during study layout. The road sites were on an existing, overgrown seasonal road that was intended to be reopened. Impacts likely on the road sites included surface grading, soil compaction, change in local surface hydrology, canopy reduction, and excavation for crossing installation. All upslope sites evidenced historical timber operations disturbance in the form of stumps and skid trails.

Table 1—Site treatment assignments and condition notes based on pre-harvest assessment of probable impacts

Road	Canopy reduction	Full operations	Controls
Rd1 - On existing seasonal road. Soil compaction from road use.	S10 - centered in swale above barely developed class III watercourse. Canopy reduction, no ground disturbance.	S3 - On historic skid trail. A tree will be dropped and skidded over the site. Canopy reduction, soil disturbance and possible compaction.	S1 - On historic skid trail; flagged as sensitive for <i>Lilium maritimum</i> population and avoided.
Rd2 - On existing seasonal road. Soil compaction from road use.	S11 - Canopy reduction, no ground disturbance.	S4 - On historic skid Site skidded over, some canopy reduction, soil disturbance and possible compaction.	S2 - On historic skid trail, area to be flagged as sensitive and avoided.
Rd3 - On existing seasonal road. Soil compaction from road use.	S12 - Canopy reduction, no ground disturbance.	S6 – Edge of historic skid trail. Site will be skidded over. Canopy reduction, soil disturbance and possible compaction.	S5 - In a swale, area to be avoided.
Rd4 - On existing seasonal road. Road widened. Grading, soil compaction from road use.	S13 – Canopy reduction to south, no ground disturbance.	S7 - On historic skid trail. A tree will be dropped and skidded over the site. Canopy reduction, soil disturbance and possible compaction.	S14 - Area within WLPZ, to be avoided.
Rd5 - On existing seasonal road in class II WLPZ. Possible excavation and widening for crossing installation. Grading, soil compaction from road use.		S8 - A tree will be dropped and skidded over the site. Canopy reduction, soil disturbance and possible compaction. Slash added to site post-harvest. S9 - Site in skid trail related ditch. Site to be skidded over, soil disturbance- ditch not to be maintained- hydrography change and slash added to site post-harvest.	S15 - Area to be avoided.

During the first week of July, 2003, and prior to any timber operations, while the plants were in flower, we recorded metadata, characterized each site, and enumerated swamp harebell. Because our study design was based on permanent plots and repeated measures, each site was benchmarked at two nearby leave trees and the distance and direction to plot center recorded to enable plot relocation in subsequent years. In addition to a benchmark description, information included Site ID; GPS location; location description; local slope (recorded from 2 m upslope or up-road to 2 m downslope or down-road at mid-plot); aspect (compass); approximate elevation (contour map); canopy cover (i.e., shade, determined with a Solar Pathfinder[®] using the template for August, one reading at mid-plot); associated species; and qualitative characterization of tree canopy (e.g., open/filtered), soil characteristics, site moisture (saturated, mesic, or xeric), habitat, and topography. Swamp harebell at each site was characterized by cover class (coded 0 for none, 1 for < 5 percent, 2 for 5 to < 10 percent, 3 for 10 to < 15 percent) in a 1 x 3 m plot (hereafter “cover plot”) oriented perpendicular to the road alignment (road plots), across draws where present, and along contour where other surface micro-topography was slight. Within each cover plot, we systematically placed five 30 x 30 cm subplots (fig. 1) in which flowering and vegetative stems were enumerated. Because the number of flowering stems was very few, this analysis sums the counts of flowering and non-flowering plants on all five subplots at each site.

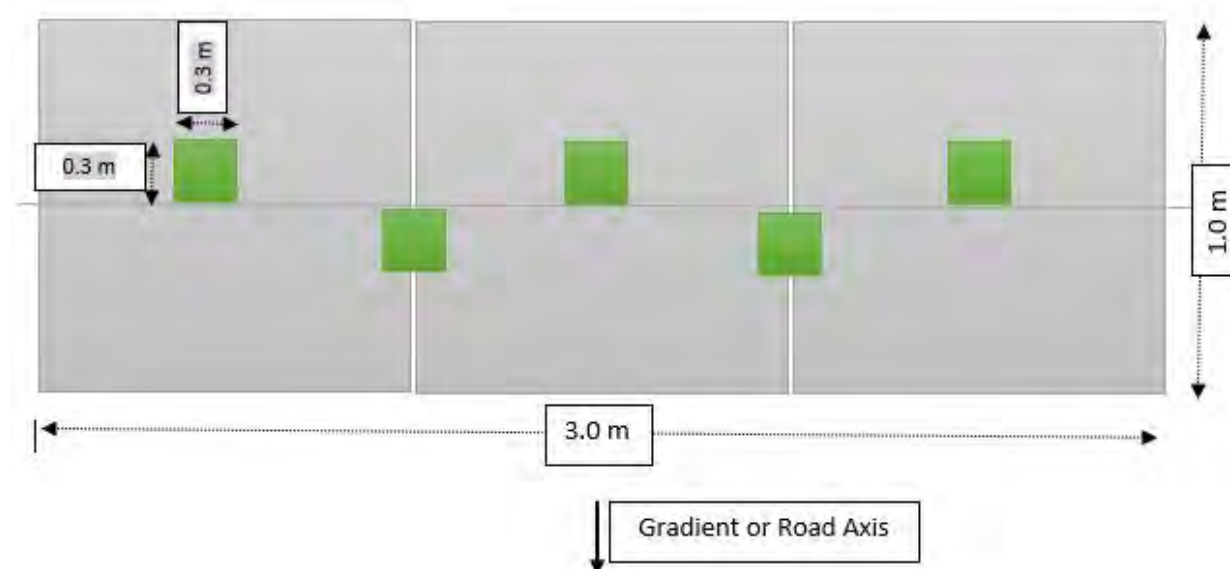


Figure 1—Layout of cover plot (1 x 3 m) and count subplots (30 x 30 cm).

Timber was harvested in 2003 immediately following the initial, pre-harvest assessment. The assessment was then repeated during early July for post-harvest years 1 (2004), 3 (2006), and 5 (2008).

Results

The solar radiation that was shaded by tree canopy was largely unaffected by the timber harvest (table 2). With the exception of one site (S8), timber operations reduced the shade among all the sites by less than 20 percent as measured the first year post-harvest (fig. 2). Within treatment categories, all the shade reduction sites experienced reduced shade in the first year post-harvest as expected, but two (S10, S13) had completely recovered by the third year post harvest. One site (S8) experiencing full operations had substantially reduced shade from pre-harvest to year 1 post-harvest, and it did not recover during the study. All other full operations sites showed stable canopy during the study period. Shade at the road sites was unaffected from pre-harvest to year 1 post-harvest and three remained stable while the fourth (R2) dropped substantially during the last year. There was no apparent trend in shade canopy for the control sites.

Table 2—Mean (SD, range) percentage of potential solar radiation during August shaded by tree canopy

Assessment Year	Control (n = 5)	Road (n = 5)	Reduced canopy (n = 4)	Full operations (n = 6)
2003	80 (10, 64-89)	85 (13, 62-96)	77 (14, 63-96)	91 (5, 85-99)
2004	78 (14, 56-94)	84 (15, 60-98)	68 (16, 56-90)	82 (13, 55-90)
2006	84 (11, 67-95)	83 (12, 66-95)	79 (8, 68-87)	86 (8, 72-93)
2008	78 (14, 54-90)	82 (18, 50-94)	80 (4, 76-84)	83 (9, 67-91)

With the exception of one site (S8), timber operations reduced the shade among the sites less than 20 percent as measured during the first year post-harvest (fig. 2).

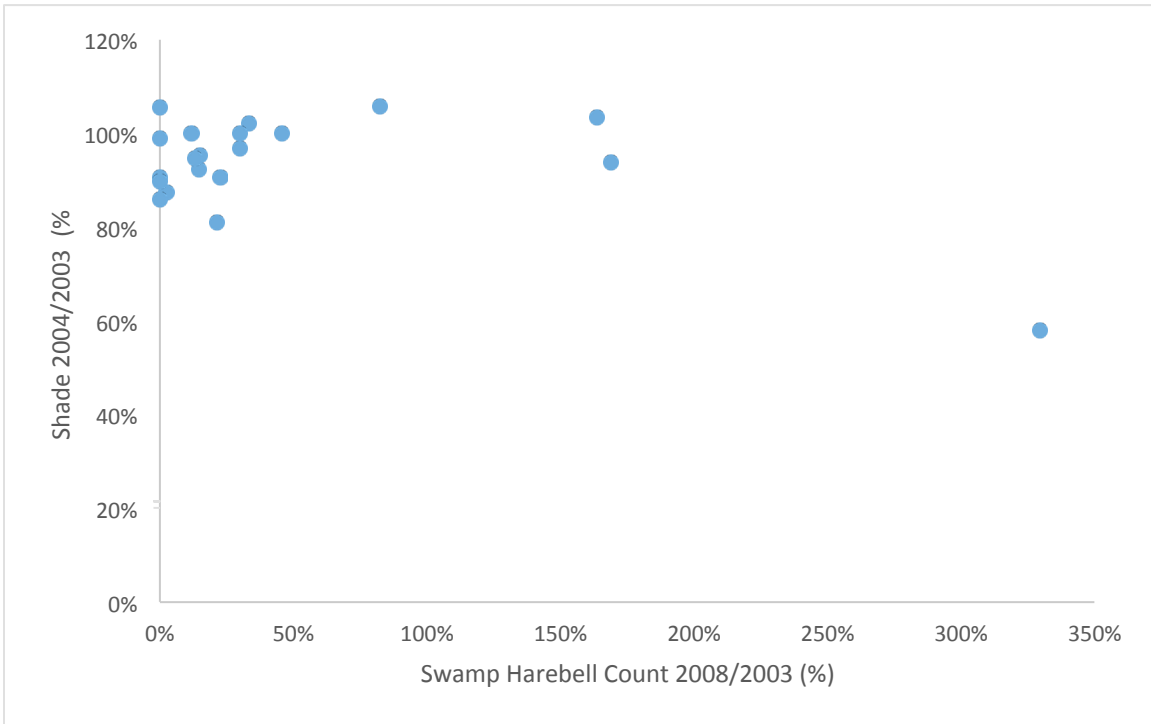


Figure 2—Percent population change from pre-harvest (2003) to year 3 post-harvest (2008) vs. change in shade from pre-harvest (2003) to post-harvest year 1 (2004).

Cover class of swamp harebell did not change from the pre-harvest to post-harvest year 1 in the shade reduction sites (fig. 3a). By the third year, all shade-reduction sites had less than 5 percent cover. The cover class was variable at sites that experienced full operations (fig. 3b). The cover class of one (S4) declined from cover class 2 pre-harvest to cover class year 1 post-harvest, and remained rank 1 for the remainder of the study. The cover class of one site (S9) was unchanged initially, but then fell to zero through the study. The greatest cover class assignment (3) was achieved during year 2 post-harvest, rising from a cover class code of 1, and then declining to a class of 2 during the final year. One site (S7) rose to a cover class 2 during the last year after three previous cover class 1 assignments. One road site (Rd 4) dropped from a cover class of 2 to 1 apparently in response to harvest, an assignment it maintained for the remainder of the study (fig. 3c). All other road sites were assigned a cover class of 1 during the entire study. Control sites (fig. 3d) showed more variability relative to the other sites, but all declined, and one (S2) was extirpated the final year.



Figure 3—Cover class over time by treatment type: A shade reduction, B full operations, C road construction, D controls.

The number of plants at shade reduction sites remained stable from the pre-harvest to the first post-harvest year (fig. 4a), but one site (S13) suffered an 80 percent decline from the first to the third post-harvest year. One site (S12) was extirpated by the final year. All sites experiencing full operation (fig. 4b) declined from the pre-harvest to the first post-harvest year, and one (S9) was extirpated. However, *C. californica* numbers at one site (S8) increased more than 8-fold between the pre-harvest and the third post-harvest. Interestingly, this site also had the greatest operations-induced shade reduction (fig. 2). With the exception of the extirpated site, trends at full operation sites suggest limited recovery at all sites by the final year compared to the pre-harvest year. Swamp harebell counts at three road sites (fig. 4c) declined from pre-harvest to year 1 post-harvest by greater than 80 percent, and they were extirpated at one (Rd 4). While the species remained present at four of five of the road sites over the study period, recovery to pre-harvest numbers was not apparent. Counts declined from pre-harvest to year 1 post-harvest at three of four control sites (fig. 4-d), more than 55 percent at one (S15). Trends appear generally negative at the control sites until the end of the study, with two control sites (S2, S15) being extirpated.

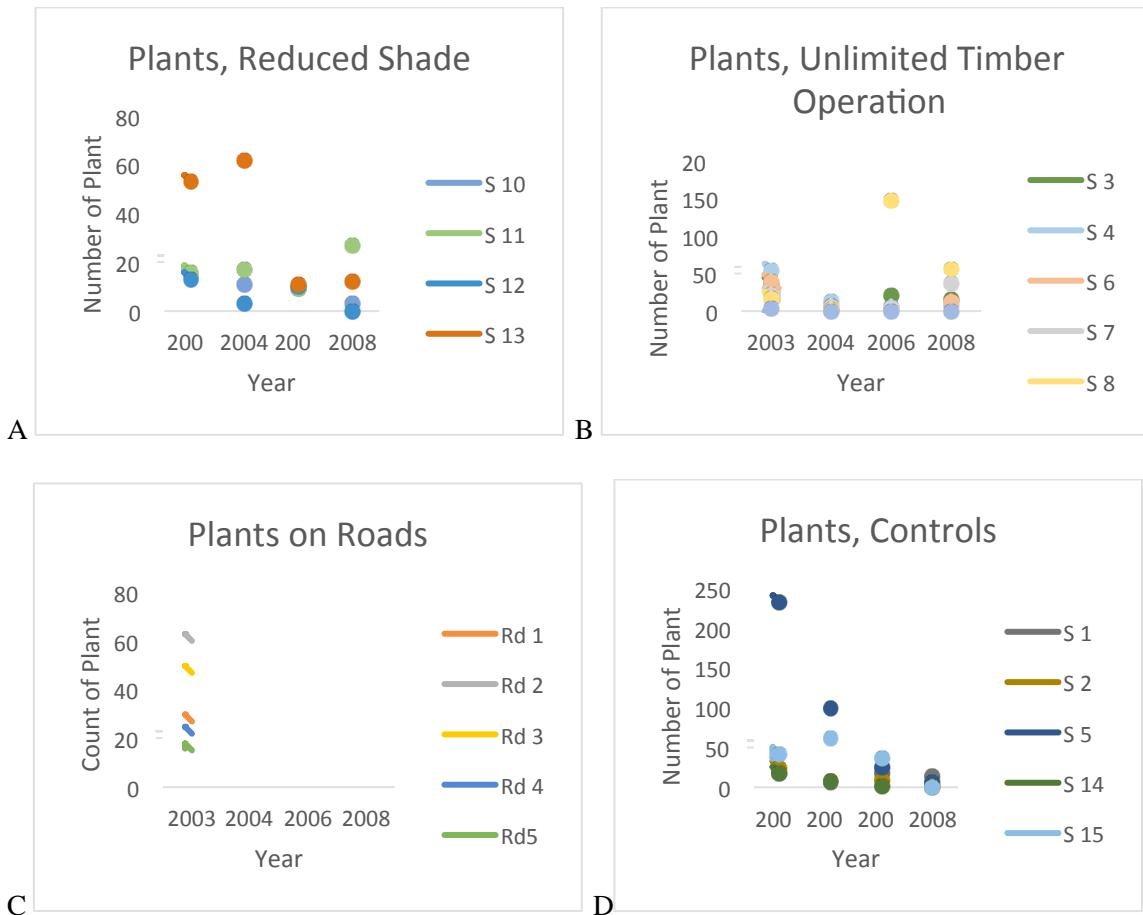


Figure 4—Plant count over time by treatment type: A shade reduction, B full operations, C road construction, D controls.

Discussion

Our study plan called for evaluating swamp harebell populations using both cover class and direct stem counts. This decision reflected the rhizomatous and clamoring growth form of the species. That is, where the species grows densely and robustly, its growth form might make direct individual stem counts so difficult that cover class becomes a more pertinent measure. However, where it grows less robustly, a direct count is not difficult. A combination of the measures, under appropriate conditions, might reveal subtle changes in vigor among sites or years. However, we found cover class to be a poor variable to assess response of harebell population size in a site. Despite being small classes (5 percent), resolution may have been inadequate. We recorded only 4 classes, one of which (class 3) was assigned at only one site and only one year. Further, we possibly mis-classed cover. To assess this possibility, we compared sub-plot counts to cover class codes (fig. 5). While there is correlation, the overlap of counts among classes is substantial. Overlap might reasonably reflect differential effects of plant vigor on the two variables, e.g., cover per plant may be greater in good rather than poor growing conditions. We cannot determine the cause of the overlap, but believe its presence underscores the importance of training and quality control to achieve repeatable and accurate measures of cover in long-term monitoring projects.

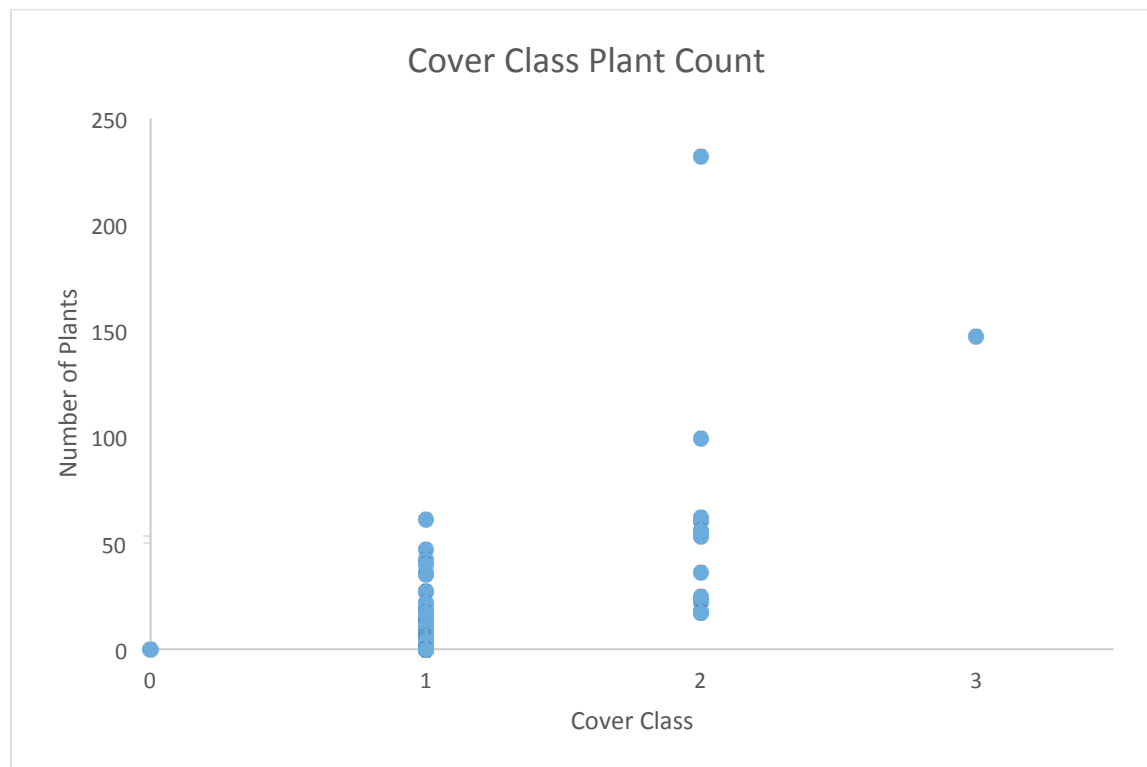


Figure 5—Plant count vs. cover class for all years, all sites.

Changes in shade did not affect the number of harebell plants. The one site with the greatest harvest-related decline in shade had the largest response in the number of plants, but this response was noted at a site where not only the shade was reduced, but trees were also felled and skidded on it. The methods used to measure shade reduction may have been insensitive to this mostly light harvest. The solar pathfinder measures solar energy blocked by vegetation between the instrument and the sun arc. Much of sun arc will remain obstructed by vegetation at low sun angles when the timber harvest intensity is light. The design with a single point measure of shade at each site may have also rendered it insensitive to the low harvest intensity. The lack of apparent relationship between canopy reduction and plant count might reflect the THPs proximity to the ocean where the marine influence on fog and temperature may ameliorate the possible desiccating effects of reduced canopy. Lastly, the species is adapted to mesic canopy openings in the coastal forest and woodland habitat (Sholars and Golec 2007), which are transitory with stand density and age or from disturbances such as fire and tree fall.

Wild pig (*Sus scrofa*) rooting impacted several sites. At the first post-harvest assessment, pigs had rooted through Rd 5 and vicinity. Although its cover class remained 1 throughout the study (fig. 3c), the count of plants dropped to 0 concurrent with the rooting, but returned to pre-harvest numbers in the third year post-harvest (fig. 4c). Pigs also rooted through a control site (S1) prior to data collection in post-harvest years 1 and 5 (2004 and 2008). Concurrently, cover class declined from the prior sampling period from 2 to 1 (fig. 3d) in both years; however, the response in the number of *C. californica* plants (fig. 4d) was not notable. The data suggests that at the intensity of pig rooting experienced, impacts to swamp harebell was immediate, but not a persistent effect at the site scale.

Only three of 20 sites had more swamp harebell plants at the end of the study than during the pre-harvest year. Five sites were extirpated and all but one of the remaining sites were occupied by less than half the pre-harvest count. The apparent strength of this timber operation impact signal is somewhat weakened by count declines observed in all the sites we assigned as “controls”, two of which were extirpated (S2, S15). Also, two of three sites (S7, S8) with increase counts of *C. californica* were in the full timber operations sites. The apparent incongruous response of harebell

numbers among treatments may in part be due to the lack of independence of the sites. Other variables such as the species short life span (Sholars and Golec 2007) may have led to variable response among the clusters.

The subjective nature of our soil and soil moisture data prevents their use in assessing impacts. However, our observations on the study sites, as well as the matrix between suggests that being able to quantify soil moisture, may well enable better impact assignment and mitigation. Examples from our study sites that soil moisture is a critical habitat parameter for swamp harebell includes the strong and consistent decline in numbers on the road sites due most likely to soil compaction, consistent with Sholars and Golec's (2007) swamp harebell timber harvest risk assessment. In comparison, the data sheet for full operations site S8 that had high cover and numbers noted comparatively moist and lush herbaceous flora and attributed it in part to harvest-generated slash in the form of spread branches retaining runoff on-site for extended periods. Further, although not quantified in any way, we observed *C. californica* clusters during post-harvest years in the matrix, often in locations of greater apparent soil moisture. Because we cannot confirm swamp harebell presence at these matrix sites prior to harvest, we cannot say if they are examples of release of on-site propagules or examples of colonization.

We only collected information on associated species within the cover plots during 1 year, and then only presence. Thus, information on changes in species composition, either through on-site release or the intentional introduction for erosion control or accidental introduction from equipment and personnel, is not discernable from our data.

Swamp harebell is generally considered a hydrophilic plant (Anonymous 2016a, Baldwin et al. 2012, Sholars and Golec 2007), and Lichvar et al. (2016) assign it a wetland status of "obligate". Thus, the species is sensitive to changes in soil moisture and hydrology. However, timber harvest impacts associated with changes in soil moisture observed from this study is further complicated by the impact of the generally unusual and drying weather over the study period (fig. 6). The Palmer Drought Severity Index (PDSI) categorizes relative drought or wetness in a way that measures both the current moisture anomaly from average adjusted with that for prior time periods – thus drought or moist period's depth and duration. The PDSI calculates a single value based on precipitation and soil moisture as measures of supply and potential evapotranspiration and soil deficit as measures of demand, and groups these values into classes that range from extreme through severe, moderate, and near normal drought or moist. The PDSI helps explain the overall decline in *C. californica* numbers (fig. 2) even at the control sites that were not subjected to on-site timber impacts (fig. 5d). Using July as the month of assessment, PDSI values reveals the pre-project data was collected during near normal but droughty conditions preceded by two years of severe to moderate drought (Anonymous 2016c). Thus, swamp harebell plants may have already been under stress at the start of the study. Two years were relatively moist, but may have not been prolonged enough to enable swamp harebell to recover from the prior dry years. All other monitoring years were under extremes of drought/moist spectrum, the final monitoring period was "extreme drought." Furthermore, the wide swings in annual climate conditions may have lead our calendar-driven inventory schedule to be more variable than a phenologically-driven inventory.

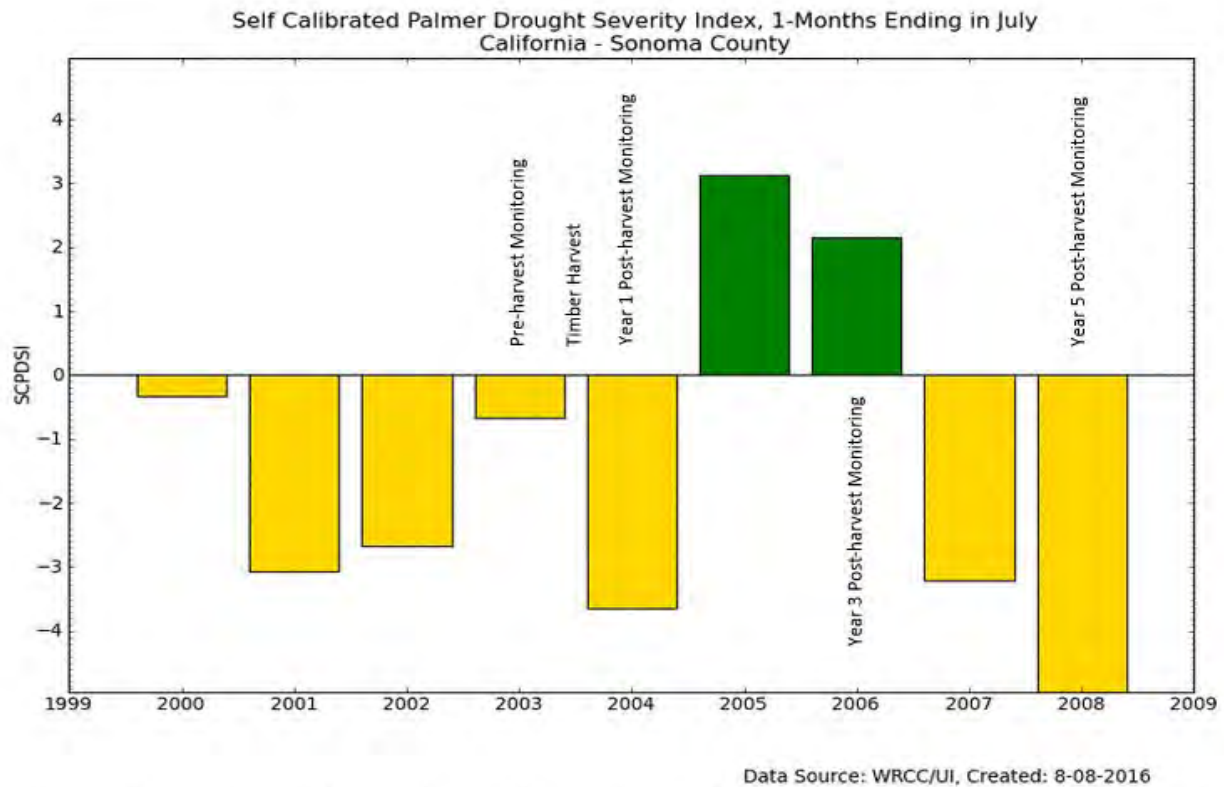


Figure 6—Palmer Drought Severity Index for Sonoma County from 2000 (3 years prior to study initiation) through 2008 (final year of study).

Despite a few notable exceptions, our results suggest a decline in *C. californica* numbers possibly as a response to timber operations when measured at the site scale. The species presence in this second-growth forest pre-harvest was not in itself an indication of its viability and resilience to past timber management. We have no information on earlier period swamp harebell plant numbers on which we could assess long-term trends and resilience to prior management. Many variables—natural and timber harvest related, in themselves or in combination—likely contributed to swamp harebell’s post-harvest decline. For example, increases in solar insolation with partial canopy alteration and increase in seasonal moisture should have positive impacts. Otherwise, crushing or uprooting plants, changes in hydrology leading to soil drying, slash deposition heavy enough to obstruct light to the herbaceous layer, introduction and proliferation of invasive plants, soil compaction, and herbicide application are expected to have negative impacts (Sholars and Golec 2007). To ensure the persistence of swamp harebell in managed timber lands, a better knowledge of its habitat, life history, and response to disturbance across the species range and under a range of climatic conditions is needed. Such knowledge will enable timber managers to more effectively manage timberlands to promote swamp harebell viability.

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