SUMMARY OF BIOLOGY AND CONTROL METHODS IN THE PACIFIC NORTHWEST FOR *GERANIUM LUCIDUM* – SHINY GERANIUM

June, 2015

Report by:
Jill Hooghkirk, Inventory Biologist
Friends of Ridgefield National Wildlife Refuge
Ridgefield National Wildlife Refuge
P.O. Box 457
Ridgefield, WA 98642
Email: jill_hooghkirk@fws.gov
Phone: 360-887-3883

Project Direction:
Lynn Cornelius, Habitat Restoration Coordinator
Friends of Ridgefield National Wildlife Refuge

Funding for this report was provided by a Fiscal Year 2014 U. S. Fish and Wildlife Region 1 Invasive Species Control Program Grant.

Purpose of this Report

This project was intended to gather and summarize information on the biology of the invasive plant shiny geranium (*Geranium lucidum*) in the Pacific Northwest through a search of the scientific literature, review of unpublished documents and agency reports, and communications with experts and local invasive plant practitioners. Information gathered is for the purpose of educating future management strategies towards effective control of this challenging invasive species. This report was part of a U. S. Fish and Wildlife Region 1 Invasive Species Control Program Grant for Fiscal Year 2014.

Key specific questions to be considered were:

- How long is the seed viable?
- Are there more than one generation of seedlings emerging during a year on the same site?
- What control methods have been tried and with what results?
- What is the role of the plant in Europe and native range?
- What is the status of invasion in other parts of the country/world?

Geranium lucidum – Shiny Geranium

Scientific name: *Geranium lucidum* (L.)

Family: Geraniaceae

Common names: Shiny geranium, shiny crane's-bill, shining geranium, shiny-leaf geranium, shiny-leaf hawksbill

Description

Geranium lucidum is a Eurasian herbaceous forb that is low-growing annual or winter annual. It is currently invading ash/oak groves, upland oak woodland savannah, riparian corridors, forest edges, roadsides and pastures in North America.

Leaves: Shiny, waxy, round to kidney-shaped with 5-7 lobes averaging 1.5 inches wide. Stipules are between 1.5-2 mm long, broadly lanceolate and hairless. Petioles are pubescent on one side.

Stems: Typically ascending, often reddish and not hairy, up to 20 inches tall. Stalk branched and fragile. The plants are very conspicuous in senescence because of the brilliant red coloring of their stems.

Roots: Taproot slightly branched, whitish.

Flowers: Small, complete, pink, 5-petaled flowers that grow in pairs on small stems. Sepals are keeled with noticeable ribs. Bloom in spring to late July. Flowers produce 5 seeds per flower.

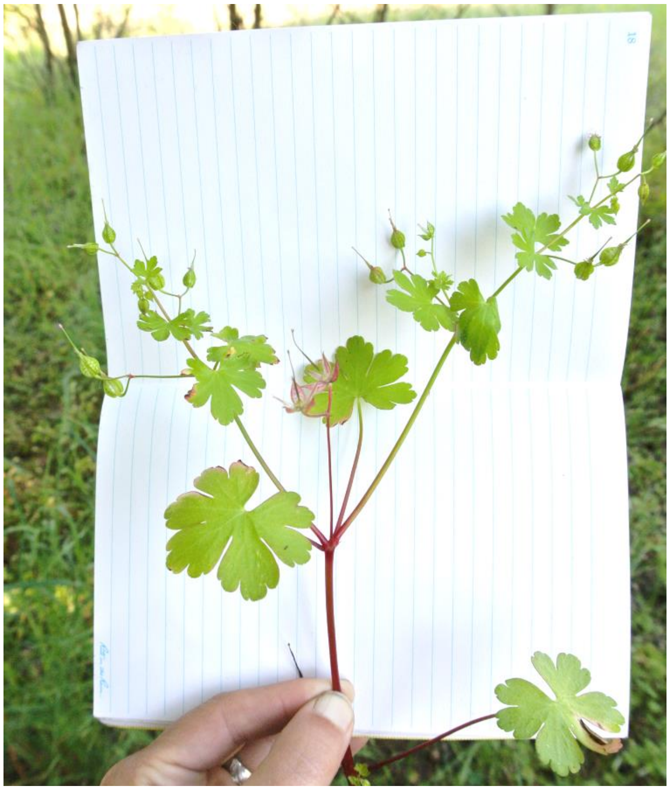

Figure 1. Samples of *G. lucidum* from sand spoils on the Ridgefield National Wildlife Refuge.

Biology

Seeds: The carpels are pubescent with tiny hairs. Seeds are 2 mm long, oval-shaped, glabrous, and reddish with black projection. The seeds form in capsules that are forcefully ejected when ripe up to 20 ft without wind. The range of seed production from flowers observed in a population on the Ridgefield National Wildlife Refuge ranged from 60-730 seeds per plant. *G. lucidum* is a prolific seeder, with nearly 100 percent seed viability (Maze 2015) evidenced by quick expansive invasion from just a few plants.

Germination: Seedlings germinate after first substantial fall rains. The fall germination emergence allows early dominant coverage of space available, preventing later emergence of native perennials or annuals (Maze 2015). Multiple spring generations (1-3) are possible depending on moisture conditions and space competition (Yeo 2004). Practitioners working with this plant in Oregon and Washington have confirmed the multiple generations in a year phenomenon displayed by *G. lucidum* (Labrecque 2015, Nemens 2008, Alfriend 2008, Halpern 2008, Miller 2015, Van Zuuk 2014). Plants germinated in the fall are fully developed in spring, flowering in April or May. Plants germinated in the spring present a truncated development and may have flowers before cotyledons are dead (Yeo 2004). When stressed (either by herbicide treatment or damage), plants were observed accelerating their life cycle to set seed as quickly as possible (Van Zuuk 2014, Alfriend 2008).

Seed Viability: The seed coat is water-impermeable and needs to be scarified in order for the seed to germinate with most permeability reached at three months after seed dispersal (Van Assche and Vandelook 2006). Results from a thorough search of the literature available found that very little published research exists on seed viability for shiny geranium. Anecdotal observations from invasive plant control practitioners in Oregon and Washington who have experience with this species have estimated the seed to be viable for at least two years in our climate (Labrecque 2015, Maze 2015, Miller 2015, Van Zuuk 2014). Maze (2015) reported that *G. lucidum* seeds are not long-lived for a forb and the seeds produced by a single plant most likely germinate within the first year or two. Grime *et al*. (1981) found that 45% of the seed tested germinated after 12 months in hermetic air-dry storage at 5 degrees Celsius. Van Assche and Vandelook (2006) concluded that three months after dry-storage, 74.2 percent of the seeds germinated and by 12 months 99.9 percent of the seeds germinated with faster germination rates at lower temperatures, typical for a winter annuals. Viability in natural conditions in the soil is estimated to be 1.5 to 2 years (Van Assche and Vandelook 2006). The oldest viable age observed has been 14 years under long-term IPGRI storage preferred conditions (-18 degrees Celsius or less in air-tight containers at a seed moisture content 5 ± 1%) at Royal Botanical Gardens Kew, Wakehurst Place (Royal Botanic Gardens Kew 2015).

Distribution

Native Range: *Geranium lucidum* is native to Europe, northern Africa, southwest and central Asia, and temperate Himalaya (Aedo 2000; eFloras 2015). The species occurs on seashores, cliff habitats, shallower, drier, base-rich soils, highly enriched lowland streams, rocky ground, limestone areas in Britain, stony hillsides, hedges, and walls (Dunn 1905, Cooper 1997, Ferreira and Moreira 1999, Stace 2010, Yeo 2004). It has also been observed growing procumbent (Ennos and Fitter 1992). *G. lucidum* prefers relatively high summer temperatures, long growing periods and a long, frost-free autumn. It also prefers nitrogenous soils and shaded environments such as broad-leaved forests. In its native range, *G. lucidum* is primarily found as a wildflower of country lanes, wasteland and garden boundaries.

Non-Native Range: *G. lucidum* has been identified as a non-native species in North America including: British Columbia, Washington, Oregon, and California. It has also been introduced in Australia (Randall 2007) and New Zealand (Howell and Sawyer 2006). *G. lucidum* has invaded ash/oak groves, upland oak woodland savannah, riparian corridors, forest edges, roadsides and pastures in North America. Shiny geranium was found in 2013 under cottonwood trees and deciduous forest edges on dredge sand spoils along Columbia River shoreline at the Ridgefield National Wildlife Refuge. Shiny geranium is a Class B Noxious Weed in Washington State due to its limited distribution in parts of the state and the potential for significant impact to state resources should it spread to uninfected areas. In Oregon, the plant is a B Listed Weed - Limited to intensive control at the state, county or regional level as determined on a site specific, case-by-case basis.

Invasive Threat

G. lucidum was first identified in the United States in 1971 from a cow pasture in Oregon (Dennehy *et. al*. 2011. It is reported to be a nursery escapee (DiTomaso and Healy 2007). Since its initial discovery, the plant has spread into habitats previously more resilient to invaders, such as dry, shallow, rocky soils found in oak woodlands (Maze 2015). *G. lucidum* has naturalized in 15 counties in Oregon (ODA 2015), five in Washington (EDDMapS 2015) and three in California (Calflora 2015). It generally appears to be more invasive in moist habitats (Shaw 2013) likely due to the moist conditions required for germination.

Several biological factors utilized by *G. lucidum* enable the small plant to pose a considerable threat to native habitats. Once established, high seed production and fall emergence enables *G. lucidum* to spread rapidly, dominate, and persist at a site. A single plant can produce 60-730 viable seeds which are capable of traveling up to 20 feet with no wind assistance. At this production level, a site may be completely re-vegetated by a few plants missed during treatment procedures. Seeds can also travel on animals, vehicles, or people interacting with a contaminated site. Plants found growing below the average seasonal Columbia River high water mark of tidally influenced basalt outcropping shoreline at the Ridgefield National Wildlife Refuge suggests that the seed is capable of traveling by water sources as well (Cornelius 2015). Van Zuuk (2014) observed the plant interspersing into established grass and setting and growing seed in moss.

Fall emergence allows the plant to dominate the space available, growing and establishing a dense carpet cover before later-emerging native herbaceous plants have a chance to grow (Maze 2015). If no disturbance occurs to the site, the plant will continue to grow though the spring, develop flowers, and set seed. If a disturbance to the population does occur while moisture is still readily available in the habitat, *G. lucidum* seedlings will germinate in the opened space. The advantageous multigenerational nature of the plant causes many controls to appear ineffective due to healthy plants growing in treated sites just a few months after treatment. *G. lucidum* is also capable of re-sprouting from remnant roots (Bongio 2015) and mechanically treated plants (i.e. mowing or weed-whacking) (Van Zuuk 2014). Plants not completely killed by herbicide treatment have also been observed to accelerate their life cycle to set seed as quickly as possible (Alfriend 2008).

Management

Several methods have been used to manage *G. lucidum* populations in the Pacific northwest including: mechanical methods (hand pulling, mowing, weed-whacking, tilling, covering), herbicides and fire (flamer). Results from treatments vary based on the accuracy of controlling all plants, potential for recolonization from plants nearby, seedbank, and amount of treatments per year. These four items must be addressed to successfully eradicate *G. lucidum* populations.

Control Method Accuracy: Treating every plant in a desired area is significant to reducing the potential for future populations of *G. lucidum*. Complete treatment will stop the seedbank accumulation for that season. Regardless of the method of control used, all plants must be killed before or when the flowers first bloom due to the short time interval between blooming and seed production. Due to the high production and viability of seeds, leaving only a few *G. lucidum* plants can repopulate the treated area.

Recolonization Potential: Recognizing populations that are adjacent to target treatment areas is important for estimating the success of eradication from a site. An area may be completely cleared of *G. lucidum* through several years of intense effort but if a population of plants exists nearby, the potential for recolonization is high.

Seedbank: The general response from practitioners and researchers working with *G. lucidum* in the Pacific Northwest estimate that seeds are viable up to two years. Treatment efforts should focus on the most recently invaded areas to stop seeds before a seedbank can be established, requiring fewer years to eradicate the area of plants. A longer, thorough commitment is required to treat areas with abundant seedbank buildup from multiple years of propagation from untreated plants.

Treatments per Year: Regardless of the method used to control plants, multiple treatments (up to 3-4) need to be applied repeatedly at the site. After treatments, the multigenerational adaptation of the plant allows seedlings to germinate and grow where competition has been removed. Also, within the same generation there may be plants that mature quicker or slower than others. Follow-up with treatment as many as 4 times per year typically after spring germination, during flowering, again at fall germination, and then late fall flowering. .

Intense treatment of a site following the recommendation above should occur consistently for a minimum of three years. The main goal for treatment is to find and destroy all plants that survive to the flowering stage to stop the species' ability to add to the seedbank (Dennehy *et. al*. 2011).

Mechanical Methods

Hand pulling: Removing entire plant and root systems by hand pulling and bagging plants to prevent seed escape. Best time to pull is right when the plants go to flower.

Pros: Hand pulling of *G. lucidum* is easy because it is an annual with a slender taproot.
Easy to apply method in new infestations of very small populations.
Volunteers able to help in public areas.
Easy to target specific plants.

Cons: Re-sprouting is possible from root remnants (Bongio 2015).
Multiple treatments required to remove plants growing due to the removal of competition (Van Zuuk 2014).
Area may be readily repopulated if untreated populations are nearby (Heckeroth 2015).
Not feasible for large populations of plants consisting of thousands to millions of individuals.
Seed can be transported on workers.

Machinery: Using rototillers, mowers, line-trimmers, or weed-whackers to cut or dig up the plant.

Rototilled and covered with bark mulch – No effect by the following year
John Bredesen, President of Board for Eugene Masonic

Mowed plants – No effect as plants very quickly regrow seeds below mower height.
Alan Van Zuuk

Weed-whacked plants – No results documented yet
Kurt Heckeroth - Salem Tillamook BLM, Oregon

Mechanical cultivation 1” deep (removed all visible plant parts after disturbing) – 90% kill rate in June, important to conduct when soil is dry enough to discourage germination.
Alan Van Zuuk

Pros: Large areas may be treated.

Cons: Damaged plants can re-sprout and develop seeds.
Plant parts may need to be collected to prevent seeds from maturing.
Seedbank still prevalent the next growing season.
Can be transported by machinery.

Fire/Flamer: Using a propane flame to burn plants down to ground level.

Pros: Can be applied during winter in damp conditions.
Easy to target specific plants.

Cons: Very time consuming.
Burnt stumps have been observed to re-sprout (Bongio 2015).
Several generations of seedling germination observed (LaBrecque 2015).
Two months after flame treatment, Miller *et al.* 2010 found that *G. lucidum* control was below 2 percent in treated areas (Figure 5).

Herbicides

Using herbicides to treat affected areas. Can be applied in the fall when plants first emerge after sufficient rains or in the early spring before native annuals and perennials emerge. Where appropriate, using an integrated weed management approach to replant treated areas with native or preferred grass or herb cover is a possible follow-up treatment to provide competition and reduce re-establishment.

Figure 2. Herbicide treated and untreated *G. lucidum* plants on the Ridgefield NWR.

Chemical Herbicides

Pros: *G. lucidum* dies with a little amount of herbicide applied.
Ideal for treating large populations.
Some herbicide treatments were the only control method where no additional seedling germination was observed, even into the following growing season.

Cons: Native vegetation may be affected by treatments
Wildlife may come into contact with herbicide.
Several applications may be necessary to treat newly germinated plants.

Figure 3. Shiny geranium treated by Weedmaster on the Ridgefield NWR. Photo taken one month after treatment. Leaves and stems are curling due to herbicide but flowers and seed are still maturing.

Table 1. Herbicide treatments applied by practitioners in the Pacific Northwest working with *G. lucidum*. Product, active ingredient, concentration, time of treatment, result, and practitioner working on the treatment are included for comparison of treatments.

Herbicide	**Product**	**Concentration**	**Timing**	**Results**	**Practitioner**
Triclopyr	Garlon 3-A	2%	Pre-flowering Late March-April	Successful	Christer LaBrecque Long Tom Watershed Council
Glyphosate	Aquamaster	2.5%		Killed targeted plants	Ginny Alfriend City of Eugene
Glyphosate		2%	Early April	Killed targeted plants	Jim Schiller City of Portland
Glyphosate	Roundup ProMAX	0.50%		Killed targeted plants	Domenic Bongio CalTrans
Glyphosinate ammonium	Reckon		November	Killed targeted plants; no spring population	Glenn Miller Oregon Department of Agriculture
Glyphosinate ammonium	Finale		Fall	Killed targeted plants; no spring population	Glenn Miller Oregon Department of Agriculture
Glyphosate + Scythe		1% of each	October	Killed targeted plants, no spring population	Dominic Maze City of Portland
2,4-D and dicamba	Weedmaster	1-2.5%	March and April	Some curling, did not kill plants	Lynn Cornelius Ridgefield National Wildlife Refuge
Glyphosate	Aquaneat	2%	February	Killed targeted plants, no re-emergence in mid-May	Lynn Cornelius Ridgefield National Wildlife Refuge
Triclopyr	Element 3A	2-3%	February and April	Killed targeted plants, no re-emergence in some sites	Lynn Cornelius Ridgefield National Wildlife Refuge

Products including glyphosate or glyphosinate ammonium appear to be effective herbicide products for treating *G. lucidum*. Treatments applied in the fall did not have a spring emergence suggesting some kind of seed suppression (Miller 2015). Maze (2015) strongly suggests treating in the fall over the spring to achieve better results. Additionally, plants dying from herbicide have been observed going to seed if they are close to or mature plants at the time of application (Alfriend 2008).

Timothy Miller, WSU Extension, tested several common herbicides on *G. lucidum* with the results in Figure 4 and Table 2. The top products tested were Oust, Crossbow, Plateau, and Arsenal. Milestone and Garlon also worked well. All of these treatments showed high control percentages even 8 months after treatment (October to June) when spring seedling germination should have occurred.

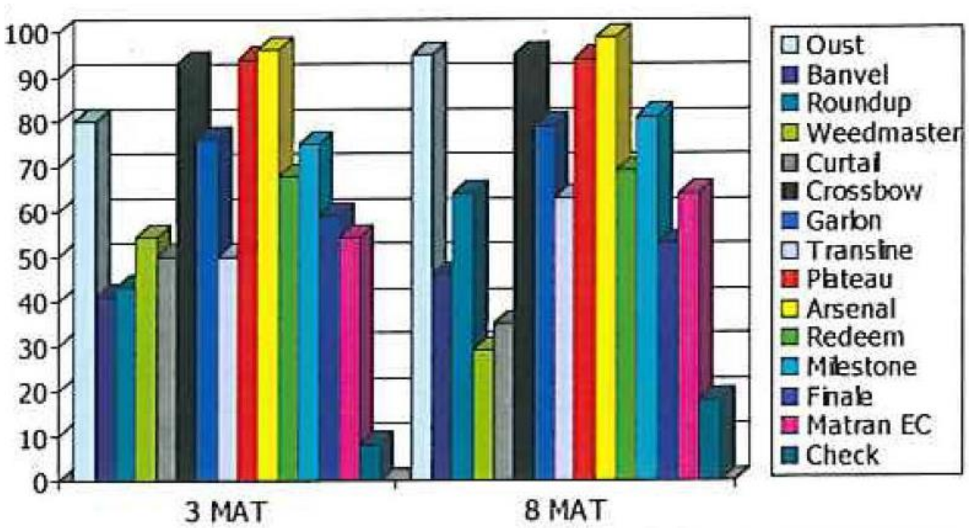

Figure 4. *G. lucidum* control after application of various herbicides at 3 months after treatment (MAT) and 8 MAT from Miller *et. al*. 2010.

Table 2. Highlighted results from Miller *et al*. 2010 herbicide tests on *G. lucidum*.

Herbicide	**Product**	**Concentration**	**Timing**	**Results**
Glyphosate	Roundup	1%	Early March	99% control by 1 month
Sulfometuron methyl	Oust	20 oz/acre	October	95% by control 8 months
Isopropylamine salt of imazapyr	Arsenal (Habitat)	16 oz/acre	October	99% by control 8 months
2,4-D and dicamba	Weedmaster		October	29% by control 8 months
2, 4-D and tricolopyr	Crossbow	4 pt/acre	October	95% by control 8 months
Triclopyr	Garlon	3 pt/acre	October	79% by control 8 months
Ammonium salt of imazapic	Plateau	12 oz/acre	October	94% by control 8 months

Aminopyralid	Milestone	3 oz/acre	October	81% by control 8 months

Organic Herbicides

Pros: Less harmful to the surrounding environment.

Cons: More expensive to apply.
Not all organic chemicals are as effective as other herbicides.

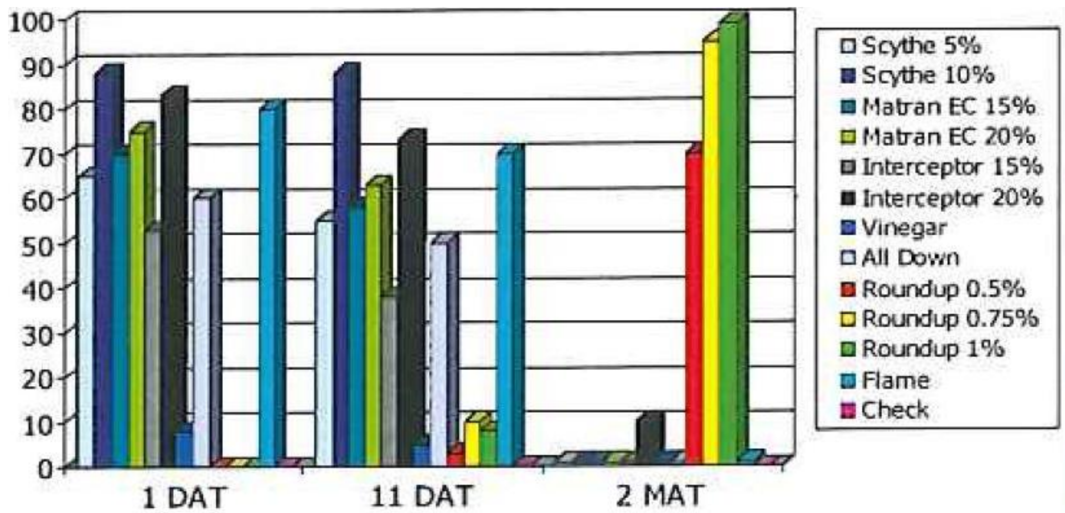

Figure 5. *G. lucidum* control after application of various oraganic herbicides, chemical herbicides, and flame at 1 day after treatment (DAT), 11 DAT, and 2 months after treatment, from Miller *et. al.* 2010.

Table 3. Organic herbicide treatments applied by practitioners in the Pacific Northwest working with shiny germanium. Product, active ingredient, concentration, time of treatment, result, and practitioner working on the treatment are included for comparison of treatments.

Herbicide	Product	Concentration	Timing	Results	Practitioner
Clove oil and citric acid with hot water	Burnout II	Full strength	February	99%	Alan Van Zuuk
Acetic acid with hot water	Ag vinegar	30%	February	100%	Alan Van Zuuk
Clove oil			Early March	10% control 1 month after	Timothy Miller
Pelargonic acid			Early March	10% control 1 month after	Timothy Miller
Pine oil			Early March	10% control 1 month after	Timothy Miller
Acetic acid			Early March	10% control 1 month after	Timothy Miller

Biological Controls

There are no approved biological control agents currently known or available.

Combinations of treatments

Some practitioners have combined several methods to treat *G. lucidum*. Alfriend (2008) found an effective combination by tilling the area first, spraying the re-sprouting plants with herbicide and then seeding with grass. LaBrecque (2015) also found that reseeding sites with native perennial cover was useful to combat *G. lucidum*.

Future Consensus

The ability for the *G. lucidum* to spread quickly and occupy many different habitats has caused many practitioners to believe most control methods are difficult, unfeasible, or even futile. Query (2015) stated that he “will probably only look to control it if I have a long-term plan to aggressively control it and occupy it with native plants”. Stewart (2015) said she doesn’t “control *G. lucidum* on most of our sties because it is too widespread”.

As with all invasive plants, if initial invasion is caught relatively early and treatment methods established immediately, there is a good probably that the plant will be contained and eventually phased out of the natural habitat. With the proper education, people working with this plant can make the correct decisions early in the game to stop *G. lucidum* from adding to the seedbank and spreading into new areas. This report is a collection of work from people around the northwest working with this plant in their perspective areas. It includes methods to consider, evaluation of various treatments, and recommendations for treating this plant

References

Alfriend, G. 2008. City of Eugene, Oregon. Personal communication to Deborah Nemens (Washington DNR).

Ardo, C. 2000. The genus Geranium L. (Geraniaceae) in North America. I. Annual species. Anales Jard. Bot. MadridSii: 39-82

Bongio, D. 2015. Personal communication. District 1 Landscape Specialist for the California Department of Transportation, California.

Calflora: Information on California plants for education, research and conservation, with data contributed by public and private institutions and individuals, including the Consortium of California Herbaria. 2015. Berkeley, California: The Calflora Database. Available at: http://www.calflora.org/, accessed May 19, 2015.

Cooper, A. 1997. Plant species coexistence in cliff habitats. Journal of Biogeography 24:4.

Cornelius, L. 2015. Personal communication. Habitat restoration coordinator for the Ridgefield National Wildlife Refuge, Washington.

Dennehy, C., E. R. Alverson, H. E. Anderson, D. R. Clements, R. Gilbert, and T. N. Kaye. 2011. Management Strategies for Invasive Plants in Pacific Northwest Prairies, Savannas, and Oak Woodlands. Northwest Science 85:329-351.

DiTomaso, J. M., and E. A. Healy. 2007. Weeds of California and Other Western States (vols. 1 & 2). University of California, Oakland, CA, U.S.A.

Dunn, S. T. 1905. Alien Flora of Britain. West, Newman, and Co., London, U.K.

EDDMapS. 2015. Early Detection & Distribution Mapping System. The University of Georgia - Center for Invasive Species and Ecosystem Health. Available at: http://www.eddmaps.org/, accessed May 19, 2015.

eFloras. 2013. Electronic Floras, online database. Missouri Botanical Garden, St. Louis, MO and Harvard University Herbaria, Cambridge, MA. Available at: http://www.efloras.org, accessed May 19, 2015.

Ennos, A. R. and A. H. Fitter. 1992. Comparative functional morphology of the anchorage systems of annual dicots. Functional Ecology 6:1

Ferreira, M. T., and I. S. Moreira. 1999. River plants from an Iberian basin and environmental factors influencing their distribution. In *Biology, Ecology and Management of Aquatic Plants* (pp. 101-107). Springer Netherlands.

Grime, J.P., Mason, G., Curtis, A.V., Rodman, J., Band, S.R., Mowforth, M.A.G., Neal, A.M. and Shaw, S. 1981. A comparative study of germination characteristics in a local flora. Journal of Ecology 69, 1017–1059.

Halpern, A. 2008. New invaders (and some not- so-new ones) to Washington state: changes to the 2009 weed list. Presentation at the Yakima Weed Conference.

Heckeroth, K. 2015. Personal communication. Botanist for the Tillamook Resources Area, Salem District BLM.

Howell, C. J., and J. W. D. Sawyer. 2006. New Zealand naturalized vascular plant checklist. New Zealand Plant Conservation Network, Wellington, New Zealand.

LaBrecque, C. 2015. Personal communication. Stewardship technician for the Long Tom Watershed Council, Oregon.

Maze, D. 2015. Personal communication. Biologist/Invasive Species Coordinator for the City of Portland Environmental Services, Oregon.

Miller, G. 2015. Personal communication. Noxious Weed Control Program for the Oregon Department of Agriculture.

Miller, T., A. Halpern, and C. Lucero. 2010. Identification and management of two invasive geraniums: herb robert *(Geranium robertianum*) and shiny geranium (*G. lucidum*). Proceedings, Weed Science Society of America, Denver, CO, in press.

Nemens, D. 2008. Assistant Natural Areas Ecologist for the Washington Department of Natural Resources, Washington. Personal communication to Ginny Alfriend (City of Eugene).

Oregon Department of Agriculture (ODA). 2015. "B" rated weeds: Shiny geranium. Noxious Weed Control Program, Salem, Oregon.

Query, T. 2015. Personal communication. Natural Resource Ecologist for the City of Portland Environmental Services, Oregon.

Randall, J. M. 2007. The Introduced Flora of Australia and its Weed Status. CRC for Australian Weed Management, Department of Agriculture and Food, Western Australia, Australia.

Royal Botanic Gardens Kew. 2015. Seed Information Database (SID). Version 7.1. Available from: http://data.kew.org/sid/, accessed May 18, 2015.

Schiller, J. 2015. Ecologist for the City of Portland Environmental Services, Oregon. Personal communication to Toby Query.

Shaw, S. 2013. Weed of the Month: Shiny geranium (*Geranium lucidum*). King County Weed News, March: 1-2.Stace, C. 2010. New Flora of the British Isles (3rd ed.). Cambridge University Press, Cambridge, United Kingdom.

Stewart, E. 2015. Personal communication. Senior Natural Resources Scientist for the Metro – Natural Resources Program, Oregon.

Van Assche, J. A., and F. E. A. Vandelook. 2006. Germination ecology of eleven species of Geraniaceae and Malvaceae, with special reference to the effects of drying seeds. Soil Seed Science 16:283-290.

Van Zuuk A. 2014. Shiny geranium control efforts log. Citizen scientist, Oregon. Report to Glenn Miller, Noxious Weed Control Program for the Oregon Department of Agriculture..

Washington State Noxious Weed Control Board, 2008. Written Findings for the Washington State Noxious Weed Control Board for Geranium lucidum. Available at: http://www.nwcb.wa.gov/siteFiles/Geranium_lucidum.pdf, accessed June 24, 2015.

Yeo, P. F. 2004. The morphology and affinities of Geranium sections Lucida and Unguiculata. Botanical Journal of the Linnean Society, 144(4), 409-429.