United States Department of Agriculture

United States
Department of
Agriculture

Animal and Plant
Health Inspection
Service

August 12, 2015

Version 1

Weed Risk Assessment for *Ficaria verna* Huds. (Ranunculaceae) – Fig buttercup

Top: *Ficaria verna* infestation and plant habit (source: Sylvan Kaufman). Middle: Aerial bulbils at the bases of plant leaves, and underground tubers (source: Leslie J. Mehrhoff, University of Connecticut, Bugwood.org). Bottom: Infestation at a local park near Washington, D.C. (source: Spencer Johnson, Invasive Plant Control, Inc.).

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Introduction Plant Protection and Quarantine (PPQ) regulates noxious weeds under the authority of the Plant Protection Act (7 U.S.C. § 7701-7786, 2000) and the Federal Seed Act (7 U.S.C. § 1581-1610, 1939). A noxious weed is defined as "any plant or plant product that can directly or indirectly injure or cause damage to crops (including nursery stock or plant products), livestock, poultry, or other interests of agriculture, irrigation, navigation, the natural resources of the United States, the public health, or the environment" (7 U.S.C. § 7701-7786, 2000). We use the PPQ weed risk assessment (WRA) process (PPQ, 2015) to evaluate the risk potential of plants, including those newly detected in the United States, those proposed for import, and those emerging as weeds elsewhere in the world.

The PPQ WRA process includes three analytical components that together describe the risk profile of a plant species (risk potential, uncertainty, and geographic potential; PPQ, 2015). At the core of the process is the predictive risk model that evaluates the baseline invasive/weed potential of a plant species using information related to its ability to establish, spread, and cause harm in natural, anthropogenic, and production systems (Koop et al., 2012). Because the predictive model is geographically and climatically neutral, it can be used to evaluate the risk of any plant species for the entire United States or for any area within it. We then use a stochastic simulation to evaluate how much the uncertainty associated with the risk analysis affects the outcomes from the predictive model. The simulation essentially evaluates what other risk scores might result if any answers in the predictive model might change. Finally, we use Geographic Information System (GIS) overlays to evaluate those areas of the United States that may be suitable for the establishment of the species. For a detailed description of the PPQ WRA process, please refer to the *PPQ Weed Risk Assessment Guidelines* (PPQ, 2015), which is available upon request.

We emphasize that our WRA process is designed to estimate the baseline—or unmitigated—risk associated with a plant species. We use evidence from anywhere in the world and in any type of system (production, anthropogenic, or natural) for the assessment, which makes our process a very broad evaluation. This is appropriate for the types of actions considered by our agency (e.g., Federal regulation). Furthermore, risk assessment and risk management are distinctly different phases of pest risk analysis (e.g., IPPC, 2015). Although we may use evidence about existing or proposed control programs in the assessment, the ease or difficulty of control has no bearing on the risk potential for a species. That information could be considered during the risk management (decision making) process, which is not addressed in this document.

Ficaria verna Huds. – Fig buttercup

Species Information

Family: Ranunculaceae

Synonyms: *Ranunculus ficaria* L. (NGRP, 2015). Because the name *R. ficaria* is still widely used, we used that name and *F. verna* during our literature review.

Common names: Fig buttercup, lesser celandine, pilewort, and ficaire (NGRP, 2015; Stace, 2010). Additional names are listed in Axtell et al. (2010).

Botanical description: *Ficaria verna* is an herbaceous perennial growing to about 25–30 cm tall and possessing tuberous roots (Stace, 2010). Heart shaped to oblong leaves form a mounded basal rosette and range in length from 4 to 9 cm long (Axtell et al., 2010). Flowers are typically yellow and rise above the leaves (Axtell et al., 2010). This species includes five subspecies, all of which are distinguishable and present in the United States (Post et al., 2009). Subspecies *ficaria* and *calthifolius* are diploid (2n=16), while subspecies *bulbifer*, *ficariiformis*, and *chrysocephalus* are tetraploid (2n=32) (Post et al., 2009). Triploids (2n=24), which are sterile and usually do not produce bulbils, occur near diploids and tetraploids and are thought to be hybrids between those two types (Stace, 2010). Subspecies *bulbifera* and *ficariiformis* produce bulbils in the axils of their leaves (Post et al., 2009). *Ficaria verna* is morphologically similar to the U.S. native *Caltha palustris*, but can be distinguished by flower morphology (Sarver et al., 2008) and the edges of the leaves (Ford, 2015; Whittemore, 2015). For a more detailed description of *F. verna* see Sell (1994).

Initiation: The Weed Specialist of the North Carolina Department of Agriculture and Consumer Services (NCDA&CS) Division of Plant Industry was asked to evaluate *Ficaria verna* for listing as a State Noxious Weed (Iverson, 2014). The PERAL Weed Team worked with the NCDA&CS's Weed Specialist to evaluate this species.

Foreign distribution: This species is native to a broad region, encompassing most of Europe (e.g., Belarus, Croatia, Germany, Ireland, Lithuania, Spain, Sweden), northern Africa (e.g., Algeria, Libya, Tunisia, and Morocco), and western Asia (Israel, Turkey, Georgia) (NGRP, 2015). It has been introduced to and is now naturalized in Australia, Japan, and New Zealand (Esler and Astridge, 1987; Howell and Sawyer, 2006; Mito and Uesugi, 2004; Richardson et al., 2006).

U.S. distribution and status: *Ficaria verna* has been present in the United States since at least 1867, when a specimen was collected in Pennsylvania (Axtell et al., 2010). It was cultivated at least 100 years ago, and possibly earlier (Snyder and Kaufman, 2004). It was probably introduced as an ornamental plant (Swearingen et al., 2002). *Ficaria verna* is currently cultivated in the United States and Canada (Axtell et al., 2010; Page and

Olds, 2001). Plant Information Online notes that seven cultivars are available commercially in the United States (Univ. of Minn., 2015), but others are likely available as well. Currently, *F. verna* is naturalized in 26 eastern states, as well as Oregon, Washington, and several provinces in Canada (CISEH, 2015; Kartesz, 2015; NRCS, 2015). Populations in the Pacific Northwest were only recently detected (Reichard, 2007), as well as a population in South Carolina (Marlow et al., 2014), indicating that the species is still spreading in the United States. The South Carolina Native Plant Society has organized a citizen watch program so that infestations can be detected early and controlled (Stringer and Marlow, 2015). *Ficaria verna* is banned, prohibited, or listed as a State Noxious Weed in Connecticut, Massachusetts, Oregon, and Washington (Anonymous, 2015; Kartesz, 2015; NGRP, 2015; NRCS, 2015).

North Carolina distribution and status: *Ficaria verna* was first reported in North Carolina in April 2005 when a voucher specimen was collected in Wake County for the North Carolina State University herbarium (Krings et al., 2005). Since then, *F. verna* has been reported in seven additional NC counties: Buncombe, Chatham, Durham, Guilford, Mecklenburg, Orange, and Swain (CISEH, 2015; Cook, 2013; Krings et al., 2005). Infestations in Sandy Creek Park, Battle Park, and the Botanical Gardens at Asheville became established from plants escaping from cultivation (CISEH, 2015; Cook, 2013; Cote, 2011). An infestation at the Bog Garden was started in 2004 when curators mistakenly planted *F. verna* instead of the similar native *Caltha palustris* (Ladd, 2013). A North Carolina nursery specializing in mail-order plants offers three cultivars for sale: 'Brazen Hussy,' 'Collarette,' and 'Orange You Cute' (PDN, 2015).

WRA area[1]: Entire United States, including territories.

1. *Ficaria verna* analysis

Establishment/Spread Potential

Ficaria verna has demonstrated a strong ability to establish and spread beyond its native range, particularly in the United States (Mehrhoff and Westbrooks, 2009; Post et al., 2009). Several factors have contributed to this ability, including shade tolerance (Taylor and Markham, 1978), an ability to form dense patches (Hammerschlag et al., No Date), sexual and vegetative reproduction (Axtell et al., 2010), self-compatibility (Marsden-Jones, 1935), and a variety of dispersal mechanisms (Axtell et al., 2010; Post et al., 2009; Reisch and Scheitler, 2009; Taylor and Markham, 1978; van der Pijl, 1982). Although not explicitly considered in our WRA model, *F. verna* is competitively superior to most other U.S. native spring ephemerals because it can emerge earlier in the season and usurp light resources (Axtell et al.,

[1] "WRA area" is the area in relation to which the weed risk assessment is conducted (definition modified from that for "PRA area") (IPPC, 2012).

2010; ISSG, 2015). We had average uncertainty for this risk element. Additional information about generation time for vegetatively reproducing plants and two persistence attributes would reduce uncertainty.
Risk score = 17 Uncertainty index = 0.13

Impact Potential *Ficaria verna* is primarily a weed of natural (Mito and Uesugi, 2004; Randall, 2007) and anthropogenic systems (Axtell et al., 2010; Richardson et al., 2006; Sell, 1994; Taylor and Markham, 1978). In natural areas it forms dense mats that exclude native species (Hammerschlag et al., No Date) and alters the structure of the understory (Snyder and Kaufman, 2004). Because it can be abundant in moist sites, it could impact Threatened and Endangered riparian taxa. In anthropogenic systems, *F. verna* is a turf and garden weed that competes with desirable species (Axtell et al., 2010; Dave's Garden, 2015). This species is controlled in both systems (Dave's Garden, 2015; Howell, 2008; Marlow et al., 2014), and several management options have been developed (Swearingen, 2010). Herbicide treatment studies have evaluated the most effective timing and concentration of herbicide applications (Hammerschlag et al., No Date). We had low uncertainty for this risk element.
Risk score = 2.8 Uncertainty index = 0.09

Geographic Potential Based on three climatic variables, we estimate that about 79 percent of the United States is suitable for the establishment of *F. verna* (Fig. 1). This predicted distribution is based on the species' known distribution elsewhere in the world and includes point-referenced localities and areas of occurrence. The map for *F. verna* represents the joint distribution of Plant Hardiness Zones 4-11, areas with 10-100+ inches of annual precipitation, and the following Köppen-Geiger climate classes: steppe, Mediterranean, humid subtropical, marine west coast, humid continental warm summers, humid continental cool summers, subarctic, and tundra.

The area of the United States shown to be climatically suitable (Fig. 1) is likely overestimated since our analysis considered only three climatic variables. Other environmental variables, such as soil and habitat type, may further limit the areas in which this species is likely to establish. Our literature review showed that *F. verna* prefers moist sites (Axtell et al., 2010). It occurs in damp meadows, shady lawns, forests, ditches, drainage ways, hedgerows, floodplains, alluvial woods, shaded turf, stream and riverbanks, pond margins, bogs, and marshes (Axtell et al., 2010; Sarver et al., 2008; Taylor and Markham, 1978).

Entry Potential We did not assess the entry potential of *F. verna* because it is already present in the United States, where it is widely naturalized (NRCS, 2015; Weakley, 2012).

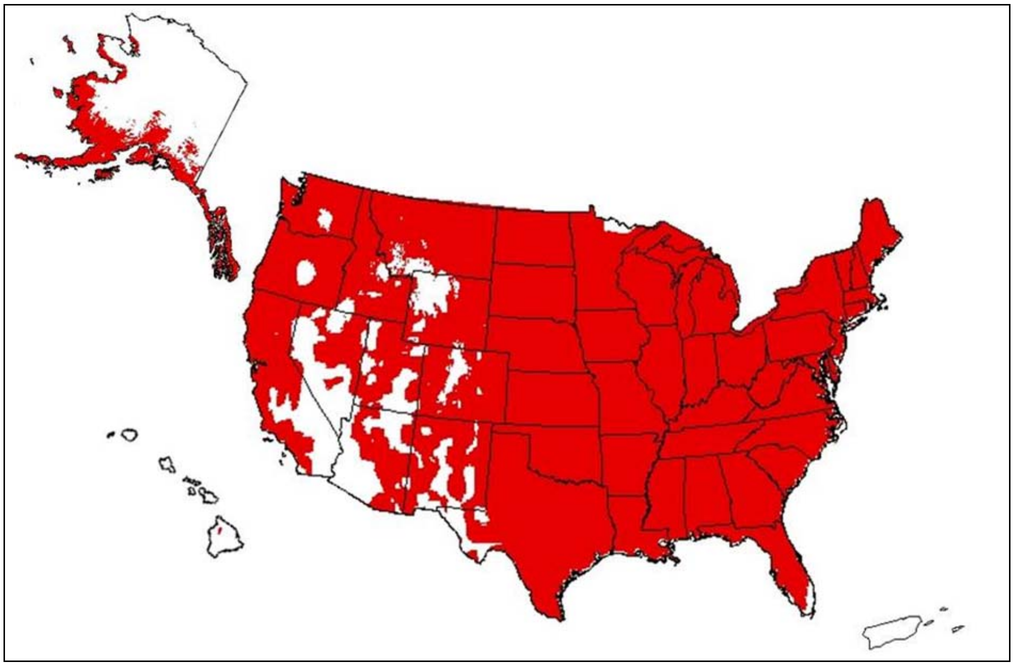

Figure 1. Predicted distribution of *Ficaria verna* in the United States. Map insets for Alaska, Hawaii, and Puerto Rico are not to scale.

2. Results

Model Probabilities: P(Major Invader) = 82.6%
P(Minor Invader) = 16.8%
P(Non-Invader) = 0.6%
Risk Result = High Risk
Secondary Screening = Not Applicable

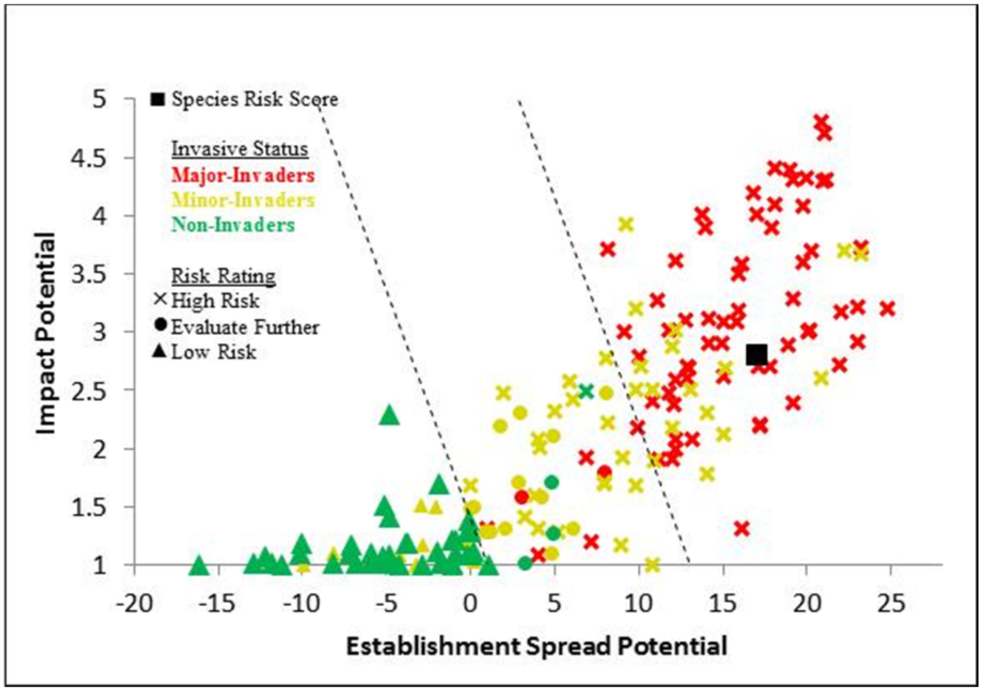

Figure 2. *Ficaria verna* risk score (black box) relative to the risk scores of species used to develop and validate the PPQ WRA model (other symbols). See Appendix A for the complete assessment.

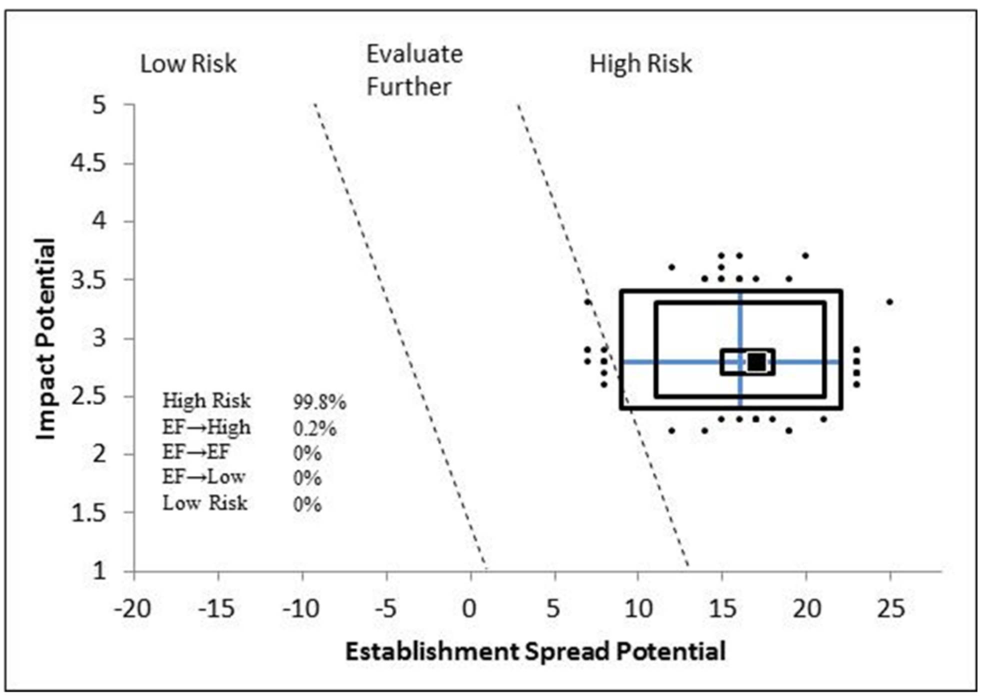

Figure 3. Model simulation results (N=5,000) for uncertainty around the risk score for *Ficaria verna*. The blue "+" symbol represents the medians of the simulated outcomes. The smallest box contains 50 percent of the outcomes, the second 95 percent, and the largest 99 percent.

3. Discussion

The result of the weed risk assessment for *F. verna* is High Risk (Fig. 2) and our uncertainty simulation corroborated that conclusion (Fig. 3). Additional information might reduce uncertainty further, and perhaps move the risk score further into the high risk region. *Ficaria verna* has already been a significant invader in the United States that readily spreads in moist sites (Mehrhoff and Westbrooks, 2009; Post et al., 2009) and outcompetes plants in natural systems and home gardens (Axtell et al., 2010; Dave's Garden, 2015; Hammerschlag et al., No Date; Snyder and Kaufman, 2004). It is still spreading into new areas and regions of the United States (Marlow et al., 2014; Reichard, 2007), and additional impacts may emerge as it is studied further. This species should be of particular concern to natural resource managers of bottomland or other moist sites because in such habitats *F. verna* can form extensive monocultures that cover several acres (Marlow et al., 2014).

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Appendix A. Weed risk assessment for *Ficaria verna* Huds. (Ranunculaceae). Below is all of the evidence and associated references used to evaluate the risk potential of this taxon. We also include the answer, uncertainty rating, and score for each question. The Excel file, where this assessment was conducted, is available upon request.

Question ID	**Answer - Uncertainty**	**Score**	**Notes (and references)**
ESTABLISHMENT/SPREAD POTENTIAL			
ES-1 [What is the taxon's establishment and spread status outside its native range? (a) Introduced elsewhere =>75 years ago but not escaped; (b) Introduced <75 years ago but not escaped; (c) Never moved beyond its native range; (d) Escaped/Casual; (e) Naturalized; (f) Invasive; (?) Unknown]	f - negl	5	*Ficaria verna* is native to a broad region that includes Europe, northern Africa, and western Asia (NGRP, 2015; Taylor and Markham, 1978). This species is naturalized in Australia (Richardson et al., 2006), Japan (Mito and Uesugi, 2004), and New Zealand (Esler and Astridge, 1987; Howell and Sawyer, 2006). A widespread distribution in some areas of Victoria, Australia (Richardson et al., 2006) suggests it is or has readily spread there. This species has been present in the United States for at least 150 years, but increasing reports of naturalization over the last 20 years indicate it has moved out of the invasion lag phase and is now rapidly spreading across the country (Mehrhoff and Westbrooks, 2009; Post et al., 2009). It was recently detected as naturalized in the Pacific Northwest (Reichard, 2007). This species spreads rapidly once established (Snyder, 1987; Swearingen et al., 2002). Alternate answers for the Monte Carlo were both "e."
ES-2 (Is the species highly domesticated)	n - low	0	Plants are cultivated, including in the United States and Canada, with several ornamental hybrids available (Axtell et al., 2010; Page and Olds, 2001). Plant Information Online notes that seven cultivars are available commercially in the United States (Univ. of Minn., 2015), but it is likely there are others. Cultivars were developed as early as the 1500s (Kaufman and Kaufman, 2007). Plants are also used medicinally for treating hemorrhoids and scurvy (Axtell et al., 2010). The young tubers are non-toxic and can be consumed raw or prepared (Axtell et al., 2010). However, we found no evidence that the species has been highly domesticated or bred for traits associated with reduced weed potential.
ES-3 (Weedy congeners)	y - negl	1	The genus *Ficaria* includes five European and Asian species (Mabberley, 2008). Randall (2012) lists three other species of *Ficaria* as potentially weedy, but it is not clear if these are significant weeds. Because some taxonomists place *Ficaria* in the genus *Ranunculus*, we also considered congeners in that genus, which includes about 600 species (Mabberley, 2008). Dozens of *Ranunculus* taxa have been reported as weedy, escaping, or naturalized (Randall, 2012). Of these, eight species (*R. acris*, *R. arvensis*, *R. bulbosus*, *R. muricatus*, *R. parviflorus*, *R. repens*, *R. sardous*, and *R. sceleratus*) may be significant weeds based on the dozen of references Randall cites for each. Holm et. al. (1979) list five species of *Ranunculus* as serious or principal weeds of agriculture (*R. acer*, *R. acris*, *R. arvensis*, *R. calthaefolius*, and *R. repens*). *Ranunculus acer*, *R. cantoniensis*, *R. caucasicus*, *R. japonicus*, *R. lomatocarpus*, and others are considered economically significant weeds (Reed, 1977). *Ranunculus repens* is problematic in lawns and fields (DiTomaso and Healy, 2007).

Question ID	Answer - Uncertainty	Score	Notes (and references)
			Ranunculus arvensis is a troublesome invasive weed in the southeastern United States in agricultural fields and disturbed sites (Riefner and Boyd, 2007).
ES-4 (Shade tolerant at some stage of its life cycle)	y - negl	1	*Ficaria verna* occurs in disturbed shady environments (Axtell et al., 2010). "The diploid occurs in both shady and open situations, but the bulbiferous form is more local and found chiefly in shade" (Taylor and Markham, 1978). It is characteristic of woodland habitats in one part of its native range (Taylor and Markham, 1978). Although it prefers open sites, it does well in shaded ones (Taylor and Markham, 1978). Produces seed in sun or shade, but it is important to note that shade is a relative term because this species grows and blooms before tree canopies have emerged (Marsden-Jones, 1935).
ES-5 (Climbing or smothering growth form)	n - negl	0	Species is an herbaceous perennial that forms a mounded rosette of leaves (Axtell et al., 2010; Taylor and Markham, 1978). It is neither a vine nor a plant with a tightly appressed basal rosette of leaves.
ES-6 (Forms dense thickets)	y - negl	2	Forms dense, carpet-like colonies on the forest floor, particularly along streams, and other water bodies (Axtell et al., 2010). Forms dense patches (Hammerschlag et al., No Date). Dense and widespread in poorly drained lawns in Victoria, Australia (Richardson et al., 2006). Forms near solid ground cover along creeks (Snyder, 1987). Sometimes forms "pure stands" in its native range (Taylor and Markham, 1978).
ES-7 (Aquatic)	n - negl	0	Species is not an aquatic plant. It is a terrestrial perennial that occurs in woodlands, forests, and floodplains (Axtell et al., 2010; Taylor and Markham, 1978).
ES-8 (Grass)	n - negl	0	Species is not a grass; it is in the Ranunculaceae family (NGRP, 2015).
ES-9 (Nitrogen-fixing woody plant)	n - negl	0	We found no evidence that this species fixes nitrogen. It is an herbaceous perennial and not a woody plant (Swearingen et al., 2002). Furthermore, this species is not in a family known to contain nitrogen-fixing species (Martin and Dowd, 1990; Santi et al., 2013).
ES-10 (Does it produce viable seeds or spores)	y - negl	1	Seed production in *Ficaria verna* varies greatly among the different subspecies. The diploid subspecies reproduce through seed, whereas the tetraploid subspecies reproduce primarily through aerial bulbils (Axtell et al., 2010). About 63 percent of the diploid seeds are viable, whereas only 2 percent of the seeds are viable in tetraploid plants (Marsden-Jones, 1935). One researcher suggests that tetraploid plants produce very few viable seeds because valuable resources are diverted from seed production into bulbil formation (Marsden-Jones, 1935). Other accounts of seed production indicate that seeds are either rarely found (cited in Sedgwick and Cameron, 1907) or primarily nonviable (Metcalfe, 1939). Based on the extensive studies of Marsden-Jones, it seems likely that these other researchers were examining tetraploid populations. We answered yes with negligible uncertainty, because the diploid taxa produce viable seed.
ES-11 (Self-compatible or apomictic)	y - mod	1	Species biology suggests that plants are adapted for some self-pollination because "[i]n the second stage [of flowering] the inner stamens arch over and stand above the carpels ..., and

Question ID	Answer - Uncertainty	Score	Notes (and references)
			although the anthers dehisce extrorsely, failing insect visits self-pollination takes place, and if the plant is not self-sterile a small proportion of seed is set" (p. 42 Marsden-Jones, 1935). In experiments where plants were caged to prohibit access by pollinators seed set was greatly reduced (Marsden-Jones, 1935). The author concluded that plants are completely self-sterile or produce only a small percentage of seeds that would have been possible had insects effected pollination (Marsden-Jones, 1935). Self-pollination occurs in the absence of insect visitors (Sell, 1994). Another study reports that sometimes, when flowers are emasculated, embryos still develop, indicating that seeds are produced through apomixis, but it was not confirmed whether these seeds are able to germinate (Metcalfe, 1939). Some plants are either female or male only (Marsden-Jones, 1935), and thus would need cross-pollination (Marsden-Jones, 1935). We answered yes because some plants are self-compatible, but used moderate uncertainty because cross pollination is still very important for this species (Marsden-Jones, 1935).
ES-12 (Requires special pollinators)	n - negl	0	We found no evidence that this species requires specialist pollinators. One study (Masters and Emery, 2015) documented that 18 different insect pollinators visited *F. verna*, including flies. Another study noted that *F. verna* subspecies *bulbifera* is pollinated by ants (Jung et al., 2008). Pollen and nectar, which is produced at the base of the petals, are available as rewards to insects; bees, small beetles, and flies are pollinators (Taylor and Markham, 1978). Finally, in one field study of flower visitors, the author noted a wide diversity of visitors, including the European honeybee (Marsden-Jones, 1935).
ES-13 [What is the taxon's minimum generation time? (a) less than a year with multiple generations per year; (b) 1 year, usually annuals; (c) 2 or 3 years; (d) more than 3 years; or (?) unknown]	c - high	0	*Ficaria verna* is a perennial species that reproduces through both sexual and vegetative means (Sell, 1994). Diploid seedlings do not begin producing flowers until their second year (Marsden-Jones, 1935). Some plants developing from bulbils flowered in their first year (Marsden-Jones, 1935), but then their seedlings wouldn't flower until their second year. We found no information on whether plants that originate from bulbils produce bulbils in their first year, but this may be possible. We found no evidence that multiple generations occur annually, or that generation time is longer than 3 years. Consequently, we answered "c" with high uncertainty, and set both alternate answers as "b."
ES-14 (Prolific reproduction)	y - high	1	Vegetative reproduction: A local myth in England about "potato rain" relates to the fact that each leaf develops a bulbil (Halket, 1927). Plants produce on average 24.1 bulbils, of which only about 60- 80 percent "germinate" (Marsden-Jones, 1935). One plant manager estimates that plants occur at densities of about 428 plants per square meter (Manning, 2015). If all of these produce 24.1 bulbils at a 60 percent germination rate, there would be approximately 6188 bulbils produced per square meter. In another study, the maximum number of bulbils per plant that was observed was 140 (Jung et al., 2008). Sexual reproduction: "[T]he diploid produces large numbers which ripen and are shed by early June" (Taylor and Markham, 1978). In one study, the researcher collected an

Question ID	Answer - Uncertainty	Score	Notes (and references)
			average of 73 viable achenes per plant out of 20 diploid plants, representing 63 percent of the total seeds produced (Marsden-Jones, 1935). Only 2 percent of the achenes are viable in tetraploid plants (Marsden-Jones, 1935). Assuming these fecundity rates, we would need to have at least 68 diploid plants per square meter to meet our threshold of 5000 for an herbaceous species, which is realistic based on Manning's estimate of plant density (2015). We answered yes for this question, but used high uncertainty because it is not clear that all plants at the population density reported by Manning (2015) are reproducing.
ES-15 (Propagules likely to be dispersed unintentionally by people)	y - negl	1	Mowing turf may spread aerial bulbils and promote the establishment of new plants (Reisch and Scheitler, 2009). Mechanical removal is very likely to result in the spread of tubers (Axtell et al., 2010). The tubers and bulbils are spread by ploughing and digging (Taylor and Markham, 1978). One of the earliest collections from New Jersey (1898) was from ship ballast from Europe (Snyder, 1987). Plants spread from yard waste (Post et al., 2009).
ES-16 (Propagules likely to disperse in trade as contaminants or hitchhikers)	n - mod	-1	We found no evidence for this kind of dispersal. It seems unlikely that *F. verna* would contaminate most vegetable crops, since it is not a weed of row crops. However, it could invade plant beds of perennial nursery stock.
ES-17 (Number of natural dispersal vectors)	2	0	Fruit and seed description for ES-17a through ES-17e: Fruit is an achene that is about 2.5-5 mm long, and with a very short beak (Sell, 1994; Stace, 2010). Achenes occur in globular clusters (Richardson et al., 2006; Taylor and Markham, 1978). "As the plants of subsp. *chrysocephalus* die, the stalks bend over so that the falling seeds form a ring round the old plant and later produce a circle of seedlings" (Sell, 1994). Some subspecies of *F. verna* also produce aerial bulbils from leaf axils (Post et al., 2009). These can also disperse (see evidence immediately below).
ES-17a (Wind dispersal)	n - low		We found no direct evidence. This species does not possess any morphological traits typically associated with wind-dispersed seeds (e.g., wings, plumes). Also, the achenes are relatively large for wind dispersal. Consequently, we answered no with low uncertainty.
ES-17b (Water dispersal)	y - negl		This species is very common and abundant along creeks and floodplain forests (Snyder, 1987). Bulbils and tubers are easily dispersed during flood events (Swearingen et al., 2002). Dispersed by rain wash (van der Pijl, 1982). "Plants thrive in mesic environments on the banks of rivers, streams, lakes, and ponds, as well as in wetland sites. This contributes to the spread of the species along major waterways because tubers, bulbils, seeds, and small plants may be dislodged by swift-moving or seasonal flood waters and transported downstream. This method of dispersal was confirmed in the spring of 2006 in Wake County, NC, where the banks of a local stream were found infested with lesser celandine, and inspection, 1 km upstream revealed a large source population in a shaded lawn" (Axtell et al., 2010). Plants can travel extensive distances downstream in flood waters (Hammerschlag et al., No Date).

Question ID	Answer - Uncertainty	Score	Notes (and references)
ES-17c (Bird dispersal)	n - mod		We found no direct evidence. The species does not produce fleshy fruit that would be attractive to birds. However, because the achenes may nevertheless be eaten by seed-eating birds, we answered no with moderate uncertainty.
ES-17d (Animal external dispersal)	y - mod		Bulbils and tubers may be accidentally and easily dispersed by animals (Axtell et al., 2010; ISSG, 2015), but we could not find the original citations. Seeds are dispersed by ants which are attracted to elaiosomes (fat/oil bodies that attract ants) (Jung et al., 2008), but this is the only report of ant dispersal or the production of elaiosomes. We used moderate uncertainty because these were all anecdotal comments.
ES-17e (Animal internal dispersal)	n - mod		We found no evidence that animals consume plants or seeds, or any evidence of gut-passage survival.
ES-18 (Evidence that a persistent (>1yr) propagule bank (seed bank) is formed)	y - high	1	In a series of experiments, researchers showed that seeds require a resting period of a few months to fully mature, and even then only some of them germinate (Taylor and Markham, 1978). However, when the pericarp of the seed is removed, germination is much faster and reaches 100 percent after 36 weeks from the start of the experiment (Taylor and Markham, 1978). In this study, seeds with their pericarp still intact, remained intact and firm after 18 months (Taylor and Markham, 1978), suggesting that seeds may be able to persist for more than a year in the soil. Consequently, we answered yes but with high uncertainty, until long-term dormancy can be established.
ES-19 (Tolerates/benefits from mutilation, cultivation or fire)	y - mod	1	The root system produces tuberous roots (Stace, 2010) that are club-shaped and range in length from 5 mm to 100 mm long (Axtell et al., 2010). The taxon survives frequent mowing (Taylor and Markham, 1978), although growth tends to decrease under these conditions (Axtell et al., 2010). We note that disturbance by mowing increases the genetic diversity of populations in mowed meadows, probably due to greater dispersal of propagules in meadows (Reisch and Scheitler, 2009); increased genetic diversity may or may not be beneficial.
ES-20 (Is resistant to some herbicides or has the potential to become resistant)	n - mod	0	We found no evidence that it is resistant to herbicides. It is not listed on the Weed Science Society of America's database of herbicide resistant weeds (Heap, 2015). However, we note that a a close relative, *Ranunculus acris*, is reported to be resistant to two different types of herbicides in New Zealand pastures (Heap, 2015). It is unknown if *R. acris* and *F. verna* can hybridize.
ES-21 (Number of cold hardiness zones suitable for its survival)	8	0	
ES-22 (Number of climate types suitable for its survival)	8	2	
ES-23 (Number of precipitation bands suitable for its survival)	10	1	
IMPACT POTENTIAL			
General Impacts			
Imp-G1 (Allelopathic)	y - mod	0.1	In one field study, researchers found that without carbon to neutralize potential alleochemicals, *F. verna* decreased the

Question ID	Answer - Uncertainty	Score	Notes (and references)
			number and reproductive capability of native species (Cipollini and Schradin, 2011). In a later laboratory study, researchers found that ground-up leaves inhibited the germination of *Arabidopsis* in potting soil when sprayed on the soil (Cipollini et al., 2012).
Imp-G2 (Parasitic)	n - negl	0	We found no evidence that this species is parasitic. Furthermore, it is not a member of a plant family known to contain parasitic species (Heide-Jorgensen, 2008; Nickrent, 2009).
Impacts to Natural Systems			
Imp-N1 (Change ecosystem processes and parameters that affect other species)	n - high	0	We found no evidence of this impact. Given that *F. verna* can form extensive populations in alluvial habitats (see image on the cover page of this document), it is possible it may change mineral deposition and hydrology, but this has not been studied.
Imp-N2 (Change habitat structure)	y - mod	0.2	Forms extensive carpets in the forest understory (ISSG, 2015; Marlow et al., 2014). Forms near-monocultures and "has significantly altered the structure of natural plant communities" (Snyder and Kaufman, 2004). "[L]ike other woodland perennials in shade it can form a continuous carpet which tends to inhibit the colonization of the ground beneath by other species" (Taylor and Markham, 1978). We answered yes because it forms monocultures and because of the statement from Snyder and Kaufman (2004). However, we used moderate uncertainty because detailed information on how it affects habitat structure is lacking.
Imp-N3 (Change species diversity)	y - negl	0.2	Dense colonies form in moist areas and exclude other species because it emerges earlier than other species (Axtell et al., 2010; ISSG, 2015). It forms mats in forest understories that block sunlight to other spring ephemerals (Kaufman and Kaufman, 2007). Naturalists report that one park had a variety of native ephemerals prior to *F. verna* forming extensive colonies (Hammerschlag et al., No Date). A management study at that same park showed that relative to control plots, which were untreated with herbicides, native species cover increased following treatment of *F. verna* (Hammerschlag et al., No Date), demonstrating that this species suppresses native plant communities. Pollinators visit *F. verna* instead of native showy plants, reducing seed set in native plants (Masters and Emery, 2015); but it is not clear if this would lead to a change in species diversity.
Imp-N4 (Is it likely to affect federal Threatened and Endangered species)	y - mod	0.1	Because this species invades natural areas, forming dense mats and excluding spring ephemerals (see evidence in Imp-N2 and Imp-N3), it seems likely to affect threatened and endangered species. We note that this species invades floodplains and riparian areas that are known to generally contain sensitive native species.
Imp-N5 (Is it likely to affect any globally outstanding ecoregions)	? - max	0	Although this species can occur in U.S. global outstanding ecoregions (Ricketts et al., 1999 and see Fig. 1), we found no evidence that it affects ecosystem properties (e.g., nutrient cycling) or otherwise has a fundamental impact on ecosystems at large scales. However, because it does reduce native species diversity and alter habitat structure, and because it can

Question ID	Answer - Uncertainty	Score	Notes (and references)
			dominate large areas (see image on coverpage), we answered unknown.
Imp-N6 [What is the taxon's weed status in natural systems? (a) Taxon not a weed; (b) taxon a weed but no evidence of control; (c) taxon a weed and evidence of control efforts]	c - negl	0.6	It is a natural areas weed in Australia (Randall, 2007). Managed in natural areas (ISSG, 2015). Species is controlled in natural areas with herbicide treatments, but managers have not been able to eradicate extensive populations, only suppress them (Axtell et al., 2010). Controlled on conservation land in New Zealand (Howell, 2008). Herbicide treatment studies have been performed to evaluate the most effective timing and concentration of herbicide applications (Hammerschlag et al., No Date). Several management options have been developed (Swearingen, 2010). Alternate answers for the Monte Carlo simulation were both "b."
Impact to Anthropogenic Systems (cities, suburbs, roadways)			
Imp-A1 (Impacts human property, processes, civilization, or safety)	n - low	0	We found no evidence, and this impact seems unlikely for a small herbaceous perennial.
Imp-A2 (Changes or limits recreational use of an area)	n - low	0	We found no evidence, and this impact seems unlikely for a small herbaceous perennial.
Imp-A3 (Outcompetes, replaces, or otherwise affects desirable plants and vegetation)	y - low	0.1	Prevents establishment of favorable grasses in turf (cited in Axtell et al., 2010). Smothers daffodils and overruns spring ephemerals in gardens (Dave's Garden, 2015).
Imp-A4 [What is the taxon's weed status in anthropogenic systems? (a) Taxon not a weed; (b) Taxon a weed but no evidence of control; (c) Taxon a weed and evidence of control efforts]	c - negl	0.4	Establishes in yards (Snyder, 1987) and lawns (Krings et al., 2005). A weed of lawns, gardens, and horticultural plantings (Axtell et al., 2010; Richardson et al., 2006; Sell, 1994; Taylor and Markham, 1978). "*Ranunculus ficaria* is a weed of lawns, grassy paths, shrubberies, roadside verges and hedgerows" in its native range (Taylor and Markham, 1978). Forms of *F. verna* that produce bulbils in the leaves are troublesome in United Kingdom gardens (Metcalfe, 1939; Salisbury, 1961). Of the nine comments under this species in the online forum Dave's Garden, eight are negative while the other one is neutral (Dave's Garden, 2015). Overall, gardeners that have either planted this species in their gardens or have had the plant invade their yards from elsewhere, note that plants are difficult if not impossible to remove and urge others to not use this plant (Dave's Garden, 2015). One commenter said "I can't believe it is still legal to buy this plant!" (Dave's Garden, 2015). "Two other promising herbicides currently being evaluated for their efficacy on lesser celandine include a fall application of the preemergence herbicide oxadiazon in turf and the preemergence granular herbicide flumioxazin in landscape ornamentals" (Axtell et al., 2010). Alternate answers for the Monte Carlo simulation were both "b."
Impact to Production Systems (agriculture, nurseries, forest plantations, orchards, etc.)			
Imp-P1 (Reduces crop/product yield)	n - low	0	Overall, we found no evidence this species is a weed or causes any specific or significant impacts in production systems. However, we note that it occurs in rough pasture (Taylor and Markham, 1978), and that other species of *Ranunculus* are toxic under some circumstances (see Imp-P5).
Imp-P2 (Lowers commodity value)	n - low	0	We found no evidence.
Imp-P3 (Is it likely to impact	n - low	0	We found no evidence.

Question ID	Answer - Uncertainty	Score	Notes (and references)
trade)			
Imp-P4 (Reduces the quality or availability of irrigation, or strongly competes with plants for water)	n - low	0	We found no evidence.
Imp-P5 (Toxic to animals, including livestock/range animals and poultry)	y - high	0.1	Fresh plants contain compounds that are known to be toxic to most mammals (cited in Axtell et al., 2010). Leaves can be used in salads, but they turn poisonous as the fruit mature on plants (ISSG, 2015). In one case, a person who was taking extracts of *F. verna* for 10 days developed acute hepatitis and required hospitalization; once she stopped taking the supplement, her condition improved (Yilmaz et al., 2015). Toxicity in the genus is due to a glycoside (Burrows and Tyrl, 2013). The genus *Ranunculus* has a long history of various medicinal uses: some species have antibacterial, antifungal and antimutagenic effects, and some cause irritations of the digestive tract (Burrows and Tyrl, 2013). Despite that, typically large quantities of material need to be consumed for any disease to manifest and in most cases only a few animals are seriously affected. Occasionally, large numbers of livestock deaths occur, as with the loss of 150 sheep in a flock of 800 after they ate *R. testiculatus* (Burrows and Tyrl, 2013). We answered yes because the species and the genus in general can be toxic under certain circumstances; however, we used high uncertainty because it does not appear to be common.
Imp-P6 [What is the taxon's weed status in production systems? (a) Taxon not a weed; (b) Taxon a weed but no evidence of control; (c) Taxon a weed and evidence of control efforts]	a - low	0	Occurs in rough pasture (Taylor and Markham, 1978). However, we found no evidence it is considered a weed in production systems. Alternate answers for the Monte Carlo simulation were both "b."
GEOGRAPHIC POTENTIAL			Unless otherwise indicated, the following evidence represents geographically referenced points obtained from the Global Biodiversity Information Facility (GBIF, 2015).
Plant hardiness zones			
Geo-Z1 (Zone 1)	n - negl	N/A	We found no evidence that it occurs in this hardiness zone.
Geo-Z2 (Zone 2)	n - negl	N/A	We found no evidence that it occurs in this hardiness zone.
Geo-Z3 (Zone 3)	n - mod	N/A	We found no evidence that it occurs in this hardiness zone.
Geo-Z4 (Zone 4)	y - low	N/A	Two points in Finland. A few points in Austria in the Alps region. Two points in Russia. A range map for the species in Europe places it in this zone (regional occurrence data; Taylor and Markham, 1978).
Geo-Z5 (Zone 5)	y - negl	N/A	Some points in Austria, Germany, and Norway. Hardy to Zones 5-10 (Page and Olds, 2001).
Geo-Z6 (Zone 6)	y - negl	N/A	Austria, Germany, Norway, Sweden, and the United States. Hardy to Zones 5-10 (Page and Olds, 2001).
Geo-Z7 (Zone 7)	y - negl	N/A	Germany, Norway, Sweden, and the United States. Hardy to Zones 5-10 (Page and Olds, 2001).
Geo-Z8 (Zone 8)	y - negl	N/A	France, Spain, the United Kingdom, and the United States. The main bud withstands temperatures of -9 °C (Taylor and Markham, 1978). Hardy to Zones 5-10 (Page and Olds, 2001).

Question ID	Answer - Uncertainty	Score	Notes (and references)
Geo-Z9 (Zone 9)	y - negl	N/A	Ireland, Spain, and the United Kingdom. Requires a chilling temperature between 4 and 6 °C for several weeks and then warmer temperatures for reproduction (Markham in Axtell et al., 2010). Hardy to Zones 5-10 (Page and Olds, 2001).
Geo-Z10 (Zone 10)	y - mod	N/A	Some points in Portugal and Spain. Three points in Australia. Hardy to Zones 5-10 (Page and Olds, 2001).
Geo-Z11 (Zone 11)	y - high	N/A	We found some points along the coasts of Portugal and Spain. We answered yes based on the number of points, but its presence seems odd given that this species requires chilling temperature for growth. Perhaps these populations are specifically adapted to this climate. Consequently, we used high uncertainty.
Geo-Z12 (Zone 12)	n - negl	N/A	We found no evidence that it occurs in this hardiness zone.
Geo-Z13 (Zone 13)	n - negl	N/A	We found no evidence that it occurs in this hardiness zone.
Köppen -Geiger climate classes			
Geo-C1 (Tropical rainforest)	n - negl	N/A	We found no evidence that it occurs in this climate class.
Geo-C2 (Tropical savanna)	n - negl	N/A	We found no evidence that it occurs in this climate class.
Geo-C3 (Steppe)	y - high	N/A	Many points in Spain. Two points in Iran. Because this species likes ample moisture, it is likely restricted to wetter sites in this climate class. Because a range map for the species in Europe does not include most of this steppe region in Spain (regional occurrence data; Taylor and Markham, 1978), we used high uncertainty.
Geo-C4 (Desert)	n - mod	N/A	One point in each of Australia, Tunisia, and Spain. These may be erroneous records or plants may be growing in protected microsites. Because the species in general prefers moist sites, we answered no.
Geo-C5 (Mediterranean)	y - negl	N/A	Greece, Italy, Portugal, Spain, and the United States.
Geo-C6 (Humid subtropical)	y - low	N/A	Some points in the United States (MD, NC, and VI).
Geo-C7 (Marine west coast)	y - negl	N/A	France, New Zealand, Spain, and the United Kingdom.
Geo-C8 (Humid cont. warm sum.)	y - negl	N/A	Many points in the United States.
Geo-C9 (Humid cont. cool sum.)	y - negl	N/A	Austria, Germany, and Sweden.
Geo-C10 (Subarctic)	y - low	N/A	Many points in Norway and Sweden. Some points in Finland.
Geo-C11 (Tundra)	y - high	N/A	Some points in Austria, Germany, and Norway, but all coastal. A few points in France.
Geo-C12 (Icecap)	n - mod	N/A	We found no evidence that it occurs in this climate class.
10-inch precipitation bands			
Geo-R1 (0-10 inches; 0-25 cm)	n - mod	N/A	A few points in Spain. We suspect these plants occur in areas where water is impounded. Because this species prefers wetter sites, we answered no with moderate uncertainty.
Geo-R2 (10-20 inches; 25-51 cm)	y - negl	N/A	Many points in Spain. A few points in Greece and Italy. Also a range map for the species in Europe includes this precipitation band (regional occurrence data; Taylor and Markham, 1978).
Geo-R3 (20-30 inches; 51-76 cm)	y - negl	N/A	Spain, Sweden, and the United Kingdom.
Geo-R4 (30-40 inches; 76-102 cm)	y - negl	N/A	France, Germany, and Spain. In the United States it occurs in areas where rainfall is more than 800 mm annually, but can occur in drier areas if supplemented with irrigation (Axtell et al., 2010).
Geo-R5 (40-50 inches; 102-127	y - negl	N/A	France, Germany, Portugal, and Spain.

Question ID	Answer - Uncertainty	Score	Notes (and references)
cm)			
Geo-R6 (50-60 inches; 127-152 cm)	y - negl	N/A	Austria, Germany, Portugal, and Spain.
Geo-R7 (60-70 inches; 152-178 cm)	y - negl	N/A	Germany, Ireland, Spain, and the United Kingdom.
Geo-R8 (70-80 inches; 178-203 cm)	y - negl	N/A	Germany, Norway, and the United Kingdom.
Geo-R9 (80-90 inches; 203-229 cm)	y - negl	N/A	Germany, Norway, and the United Kingdom.
Geo-R10 (90-100 inches; 229-254 cm)	y - low	N/A	Norway and the United Kingdom.
Geo-R11 (100+ inches; 254+ cm)	y - low	N/A	Norway.
ENTRY POTENTIAL			
Ent-1 (Plant already here)	y - negl	1	This species is widely naturalized in the United States (NRCS, 2015; Weakley, 2012).
Ent-2 (Plant proposed for entry, or entry is imminent)	-	N/A	
Ent-3 (Human value & cultivation/trade status)	-	N/A	
Ent-4 (Entry as a contaminant)			
Ent-4a (Plant present in Canada, Mexico, Central America, the Caribbean or China)	-	N/A	
Ent-4b (Contaminant of plant propagative material (except seeds))	-	N/A	
Ent-4c (Contaminant of seeds for planting)	-	N/A	
Ent-4d (Contaminant of ballast water)	-	N/A	
Ent-4e (Contaminant of aquarium plants or other aquarium products)	-	N/A	
Ent-4f (Contaminant of landscape products)	-	N/A	
Ent-4g (Contaminant of containers, packing materials, trade goods, equipment or conveyances)	-	N/A	
Ent-4h (Contaminants of fruit, vegetables, or other products for consumption or processing)	-	N/A	
Ent-4i (Contaminant of some other pathway)	-	N/A	
Ent-5 (Likely to enter through natural dispersal)	-	N/A	