Common name: Red Sorrel (Sheep sorrel, field sorrel, sour grass, mountain sorrel)
Scientific name: *Rumex acetosella* L.
Family name: Polygonaceae
Lifecycle: Herbaceous perennial

Seedling description: Rosette basal leaves emerge in early spring. Early leaves are entire and downy, often non-lobed (Stopps et al., 2011).

Leaf shape and margins: Leaves are 3-lobed, entire, and alternately arranged. The primary lobes are arrow shaped, and lateral lobes flare from the leaf's base and are triangular. (Stopps et al., 2011).

Shoot structure: Shoots emerge from adventitious root buds that develop sporadically along horizonal roots. Adventitious root buds develop into aerial shoots (Hoeg & Burgess, 2000).

Root type and/or vegetative reproductive structures: Horizontal creeping roots that produce adventitious root buds (Stopps et al., 2011).

Flower description and flowering time: Male and female structures occur on separate plants (Piotrowska, 2008). Tepals of the male flower are obovate, and flowers are yellow in color. Female flower tepals are ovate, flowers are red/brown, and are produced in clusters on branched stocks (Piotrowska, 2008; Stopps et al., 2011). Ramets begin flowering mid to late May into mid-July (White et al., 2015).

Seed description: One three-sided, red/brown seed is produced by each flower on female plants. Seeds are surrounded by a red/brown husk. Seeds are 1.5mm in width (Uva et al., 1997). Seeds are mature by mid-August (Franzese & Ghermadi, 2014).

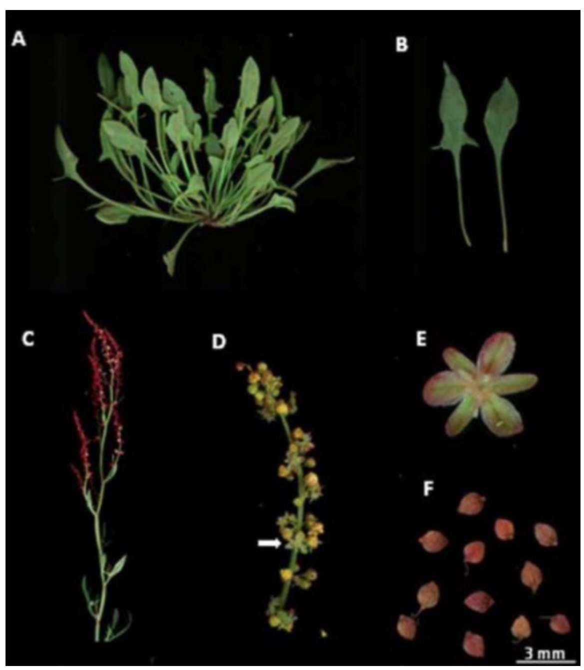

Figure 1. *Rumex acetosella* (A) basal rosette; (B) varying leaf shapes; (C) female inflorescence; (D) male inflorescence; (E) flower head; (F) seeds (Stopps et al., 2011).

Weed Biology and Ecology

Floral biology:
R. acetosella is dioecious and produces pollen that is distributed by wind and insects (Piotrowska, 2008; Houssard & Escarre, 1991). Red sorrel is visited by native pollinators as well as the introduced honeybee and seeds are produced by allogamy (Löve, 1944). Vivipary does not occur, as seeds do not typically germinate in the year they are produced (Assche & Nerum, 2002). There are some instances of agamospermous seed production under certain environmental conditions (Mulligan & Findlay, 1970).

Seed production and dispersal:
One seed is produced per flower. Seed production is approximately 250 per stem, and up to 1600 seeds per ramet (Kennedy, 2009; Escarre & Thompson, 1991). The weight per 1000 red sorrel seeds varies from 0.450 g to 0.525 g depending on growing conditions (Steves, 1932). Seeds can be dispersed by wind, water, animals, and insects. Grazing of red sorrel by ruminant animals and birds help disperse seeds. Animals and birds aid in dispersal by ingesting and discreating seeds (Stopps et al., 2011). Seeds can also be distributed by humans and harvesting equipment (Boyd & White, 2009).

Seed banks, seed viability, and seedling emergence:
Red sorrel seeds can persist in the soil for at least 5 years, and seeds can be present under dense canopy or on barren land (Fyles, 1989; Assche & Nerum, 2002). Specific requirements for red sorrel seed germination have not been reported. Seeds of R. acetosella do not germinate immediately after dispersal, but after at least a year of dormancy (Assche & Nerum, 2002). Assche and Nerum indicated a 5-8% germination rate for *R. acetosella*, with an optimal germination temperature of 17 to 30 degrees Celsius. Seed germination for red sorrel is highly dependent on light exposure during all seasons but does not display seasonal dormancy (Assche & Nerum, 2002). Removal of competing species can increase seed germination (Putwain & Harper, 1970). A study conducted by Putwain and Harper in 1970 reveled red sorrel seed readily germinating from soil from an 80-year-old stand of Eastern White Pine, although sorrel had not been observed in the recent ground cover. Fire treatments on Mediterranean species of red sorrel reveled seeds exposed to temperatures in excess of 80 degrees Celsius decreased seed survival (Franzese & Ghermandi, 2014).

Vegetative reproduction:
Red sorrel reproduces vegetatively by underground creeping roots. Roots grow horizontally within the first 7 cm of soil and produce adventitious root buds at irregular intervals along length of roots (Kiltz, 1930; White, 2013). These buds can sprout immediately after maturity, buds can arise anywhere along roots (Kennedy, 2009). This process is called root sprouting. Adventitious buds develop into stems with scale-like leaves under the soils surface, these structures then develop into aerial shoots. In established populations of red sorrel reproduction is mainly dependent on asexual reproduction via creeping roots and adventitious buds, especially where competitive vegetation is present (Kennedy, 2009; Putwain et al., 1968). Most ramets will remain vegetative during the first year after emergence (White et al., 2015), and would produce vegetatively after the first year of establishment. A study conducted in 2007 by Dr. Scott White found no significant increase in red sorrel populations after removal of grasses in lowbush blueberry fields. Seedling recruitment is considered minor to maintenance of populations (Kennedy, 2009).

Population dynamics:
R. acetosella thrives on poor, acidic soils and readily populates disturbed areas, and is an early successional species. Individual plants can live for 15 to 20 years from vegetative reproduction (Stopps et al., 2011). Red sorrel emergence is season long (White et al., 2014). It was found

that red sorrel can produce upwards of 1000 ramets per square meter in lowbush blueberry fields (White et al., 2014). In the same study, ramets that flower after overwintering, had higher survival rates than those that remained vegetative. Low survival rates of overwintering vegetative ramets were met with season long ramet emergence (White et al., 2014). White also stated that a greater density of new ramets emerged in blueberry patches as opposed to bare soil (White et al., 2014). Populations of red sorrel can increase post-fire due to nutrient input from ash, but high-intensity fires could negatively impact seed germination and seedling vigor (Franzese & Ghermandi, 2014. *R. acetosella* is known to be drought tolerant due to well-developed root systems. Male plants tend to be more drought tolerant than females (Houssard et al., 1992). A study conducted by Fujitaka & Sakai in 2007 concluded that female plants allocate most energy to above ground plant structures. While another study inferred that male plants input more energy into vegetative reproduction (Putwain & Harper, 1972). Red sorrel produces one generation per year (Hoeg & Burgess, 2000), and produce dense patches.

Economic Importance

Detrimental effects:
Red sorrel can reduce yield and easily contaminate other Christmas tree lots. Seeds can be easily transported by harvesting equipment, therefore making it difficult to reduce spread (Boyd & White, 2009). *R.* acetosella is tolerant of mowing, clipping, or grazing, and can recover fully within five months (Del-Val & Crawley, 2004). This makes red sorrel a difficult weed to manage. Can be poisonous in large quantities to grazing animals, and holds little nutritional value (Cooper and Johnston, 1984). Red sorrel can be an alternate host for disease. A study in 2003 experimentally transmitted Tomato spotted wilt virus to red sorrel (Parrella et al., 2003). Tomato spotted wilt virus can cause massive economic loss (approximately 1 billion in losses per year) across a wide range of commercial crops (Roselló et al., 1996). Rumex acetosella is known to display herbicide resistance. A study conducted in 2010 produced varying results when testing fertilizer and herbicide applications to red sorrel (Kennedy et al., 2010). Herbicide resistance can lead to reduced weed control (Li et al., 2014).

Beneficial effects:
Red sorrel could be considered for early sight recollimation efforts, since it can colonize disturbed areas quickly. Although *R. acetosella* readily populates recently disturbed areas, it is not a reliable vegetation for long-term erosion control and soil stabilization. As most of the root mass is located in the first 7 cm of soil, it would not do an adequate job at securing the lower soil profiles. R. acetosella contains numerous vitamins and organic acids (Tamayo et al., 2000). Red sorrel has been used as a traditional medicine to treat ailments such as scurvy, anemia, arthritis, and cancer (Kaegi, 1998; Korpelainen & Pietilainen, 2020). Mammals, birds, insects, and other invertebrates are known to forage on red sorrel (Stopps et al., 2011). Although and important food source for many, the act of grazing can increase population numbers of sorrel (Del-Val & Crawley, 2004).

Legislation:
Currently there are no Canadian Federal or Provincial Weed or Seed Acts that list red sorrel. It is although, listed in the United States in Iowa as a secondary noxious weed and in Connecticut as an invasive and banded species (Connecticut Invasive Plant Council, 2010; Iowa Code, 2009). Seeds of red sorrel are also restricted or prohibited across numerous states in the US (Anonymous, 2009).

Management Opportunities

Monitoring:
Although seedlings do aid in establishment of red sorrel, the main mode of population maintenance is by vegetative reproduction (White et al., 2015). Ramet emergence occurs mid to late April and reach 90% emergence by mid to late September (White et al., 2015). Therefore, the idea time to monitor for red sorrel is from April to September. Ramets produce basal rosettes, throughout the entire growing season. Early leaves are entire and downy, often non-lobed (Stopps et al., 2011).

Potential physical and mechanical control options:
R. acetosella is tolerant of mowing, clipping, or grazing, and can recover fully within five months (Del-Val & Crawley, 2004). Red sorrel can withstand low intensity fires, and populations can spike post-fire. If high intensity fire treatments are able to be utilized, they have the potential to reduce seed viability and reduce seed banks in subsequent years (Franzese & Ghermandi, 2014). Hand pulling would reduce underground structures but would be laborious and nearly impossible to remove completely in large populations. Tillage is very effective for the management of perennial rhizomatous weeds and has been used to manage Canada thistle (*Cirsium arvense* L.), in conjunction with subsequent herbicide applications, in various cropping systems (Darwent et al., 1994). Use of tillage in Christmas trees, however, is difficult due to potential damage to Christmas trees and is not widely recommended for weed control.

Potential cultural control options:
Cultural weed management involves the use of crop rotation, fertility management, cultivar selection, and other strategies that increase crop competitiveness against weeds. Cultural management practices encourage growth of Christmas trees while reducing weed occurrence (Morrison et al., 2000). Use of mulches, a cultural and mechanical weed control tool, can increase lot density and potentially make the crop more competitive with weeds. Sanderson and Cutcliffe (1991) found that sawdust mulches increased growth of many perennial species, therefore, contributing to increased competitiveness with weeds. Mulching aids soil fertility management, and by maintaining soil fertility, vigor of Christmas trees is increased (Kender & Eggert, 1966). Interplanting competitive fir cultivars could help reduce bare spots and increase genetic diversity within fields (Jones & Percival, 2003). As Christmas trees prefer acidic soil, applications can be used to lower soil pH. Maintaining proper soil pH contributes to decreased ground cover of broadleaf and grass weeds in Christmas tree lots (Smagula et al., 2009).

Potential biological control options:
Biological control employs the use of beneficial organisms that target and reduce pests. Currently, this approach for weed management is limited. Ground beetle and field cricket have been observed consuming the seeds of common weeds such as sheep sorrel and hair fescue (*Festuca filiformis* Pourr.). Cutler et al., 2016 indicated these natural enemies may contribute to weed biocontrol. Although red sorrel is a food source for many mammals, birds, and invertebrate, the plant is not consumed at high enough rates to manage populations (Stopps et al., 2011).

Potential chemical control options:
Chemical management of creeping herbaceous perennial weeds is generally very effective. These management strategies include the use of both soil-applied herbicides and foliar applied contact and systemic herbicides. Soil applied herbicides are applied to the soil prior to crop planting or applied as a pre-emergent treatment. After application, the herbicide persists in the soil and the plant absorbs the chemical through its roots. Herbicide is then transported

acropetally to emerging shoots (Nishimoto, 1971). A chemical control named 2,4-D has been used to reduce red sorrel populations but has reduced capacity on its own. A study conducted in 1960 interpreted approximately 40% control of red sorrel when treated with 2,4-D (Lorenzi & Jeffery, 1987). Dicamba can provide 85 to 100% of red sorrel on its own (Burrill et al., 1990).

Hexazinone is widely used in management and is applied as a pre-emergent treatment and provides weed control in subsequent years. It is typically applied in the spring and is activated in the soil by rainfall (Boyd et al., 2009). Hexazinone has been increasingly used to control red sorrel in many agricultural systems. Studies using hexazinone as a pre- and post- emergent herbicide for the control of red sorrel have yielded varying results. It is expected that herbicide resistant populations of red sorrel are present across the province (AAF, 2017). These resistant populations may contribute to varying herbicide efficiency results. A study in 2002 inferred that hexazinone applications during May of the fruit-bearing year in lowbush blueberries could attain 94% control of red sorrel (Jensen and Specht, 2002). Alternative application timings that reduce injury risk to Christmas trees (e.g., after trees have hardened off) could be identified and evaluated with further research. Herbicide applications should be made during primary emergence or during active growth of weeds.

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