KENAI PENINSULA COOPERATIVE
INVASIVE SPECIES
MANAGEMENT AREA

Reed Canarygrass (*Phalaris arundinacea*)
State of the Science Summary
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Table of Contents

Acronyms and Abbreviations

ADEC	Alaska Department of Environmental Conservation
C:N	Carbon to nitrogen ratio
KP-CISMA	Kenai Peninsula Cooperative Invasive Species Management Area
RCG	Reed canarygrass
v/v	Volume concentration, or volume per volume

Overview

To further understand the current state-of-the science regarding reed canarygrass (*Phalaris arundinacea*, herein abbreviated as RCG), the Kenai Peninsula Cooperative Invasive Species Management Area (KP-CISMA) implemented a literature review focused on the past decade of published research. Below are major findings compiled by topic.

Methodology

This literature review was conducted in December 2020. Google Scholar was used to search for journal articles published between 2010 and 2020, beginning with the search term *Phalaris arundinacea*. A brief internet search was also conducted with the same search terms. Numerous papers on RCG have been published in the last ten years. The Google Scholar query for *Phalaris arundinacea* returned approximately 14,200 results. A query for *Phalaris arundinacea* + *Alaska* produced 715 items. A search for *Phalaris arundinacea* + *economy* OR *economics* yielded 5,110 papers. All search results were sorted by relevance, and the top 50 articles for each query were assessed for relevancy. Ultimately, 18 journal articles and 14 non-journal resources were reviewed in detail, as they were germane to this KP-CISMA state-of-the-science assessment of RCG.

Although search parameters were defined for 2010-2020, often these documents reviewed reference older work. Within this document, where applicable, the original citation is provided parenthetically, and as such may reference research conducted prior to 2010.

Resources that were dismissed focused primarily on using RCG for phytoremediation or biofuel; a few were omitted that focused too specifically on genetics. Of the resources considered in this assessment, they covered topics that could be organized into eight categories: biotic impacts, abiotic impacts, control and management strategies, herbicide trials, remote mapping, genetics and phenotypic plasticity, biological characteristics, and landscape invasibility.

Major findings

Studies examining impacts to biotic communities include insects, arthropods, wetland plants, trees, birds, mammals, and fish. However, studies show mixed effects on most organisms, with consistently negative impacts reported only for wetland plants and fish. Abiotic impacts include deposition and sedimentation; changes to soil structure, content, and hydrology; reduced landscape heterogeneity and microtopography; creation of a thick sod and litter layer; decreased water velocity, decreased dissolved oxygen, increased water temperature; and alteration of nutrient cycling.

Many management and control strategies have been tested and evaluated (chemical, mechanical, and cultural), but there are no studies specific to Alaska. The methodologies used in other studies may be a valuable resource for duplication studies locally. Some of the findings from outside the state may be applicable in Alaska, but more research is needed. Other states have also used remote mapping, and previous methodologies may help inform a mapping protocol for the Kenai Peninsula.

Major genetic findings include the range of documented infraspecific species (~10), cultivars (~11) and genotypes (~386), mostly within populations rather than between them (see sidebar/footnote; Nelson et al. 2014, Lyons 2014). This explains some of the biological characteristics of RCG, specifically the variation in morphology and environmental response of populations. For example, while RCG is primarily a wetland species, it can produce highly competitive, monotypic stands in mesic to dry sites and shaded areas (Henderson 1991 as cited in Lyons 2014). Genetic diversity likely contributes to the invasiveness of RCG by increasing phenotypic plasticity and adaptation to a variety of environments.

> **Infraspecific species:** Any taxon below the rank of species. For example, subspecies, variety, subvariety, form, subform.
> **Cultivar:** Cultivated plants selected for desirable traits. A cultivar name can be applied to a genus, species, or any infraspecific taxon.
> **Genotype:** A set of heritable genes in an organism.
> **Phenotype:** Observable traits of an organism (development, morphology, behavior), as determined by genotype, epigenetics, and environmental factors.

In addition to the invasiveness of this species, the invasibility of a landscape influences establishment. Factors that encourage invasion include natural or anthropogenic disturbance, canopy gaps, neighboring agricultural areas, high nutrient addition and sedimentation rates within a wetland, and clay/loam or sandy soil. One study shows that emergent open canopy wetlands are most prone to invasion. Other studies indicate inconsistent results regarding flooding and saturation levels associated with RCG establishment and success.

Biology and ecology

Alaskan introduction and growth habit

Reed canarygrass was introduced to Alaska in the 1970s for soil stabilization and as a forage crop. At that time, it was believed RCG seed lacked viability, which turned out to be false (Galatowitsch 2007). It can grow up to six feet tall and is biennial in regard to flowering. Growth peaks twice, in late spring and late summer, with a mid-summer dormancy period. The first peak correlates with inflorescence and leaf growth, second peak correlates with rhizome and stem growth (WRCGMWG 2009). RCG can thrive in wetland environments by focusing on shoot growth in flooded conditions, then switching to lateral spread as the area dries (Galatowitsch 2007). This grass is inefficient at obtaining and utilizing nitrogen, therefore growth increases with nitrogen addition relative to native plants (Perry et al. 2004, as cited in Galatowitsch 2007).

Propagation

Reed canarygrass reproduces by seeds and rhizomes. Seedling establishment may be less common than vegetative reproduction because seedling establishment requires high light (canopy gaps), whereas vegetative spread can tolerate low light (Maurer and Zedler 2002, as cited in Galatowitsch 2007). Additionally, rhizomes can grow horizontally over ten feet per year and are better adapted to survival and spread in inundated conditions. In conditions that allow for seedling germination, new seedlings typically only require one season to establish (WRCGMWG 2009). Germination is most successful after human or natural disturbance, in canopy gaps, and in saturated soils (Lavergne and Molofsky 2004).

Shortly after floods, RCG persists in the form of floating mats, which produce nodes that fragment and spread to colonize new areas (Lavergne and Molofsky 2004). Studies have produced contradictory results regarding the ability of RCG vegetative portions to tolerate prolonged inundation. For example, Hutchison (1992) found they were intolerant, whereas LeFor (1987) found that rhizomes tolerated extended periods of flooding; however, many studies indicate a reduced viability of seeds with prolonged inundation (as cited in Lyons 2014). Most seeds either germinate or decompose within three months of inundation, but occasionally germination rates remain high for up to one year following inundation; after 48 months of inundation seeds are no longer viable (Comes et al. 1978 as cited in Lyons 2014). Consequently, long periods of flooding may eliminate viable seeds from soils (Lyons 2014). However, there is a lot of variable information on seed viability. For example, some reports indicate seeds are short-lived and germinate in 10-21 days, with poor germinations rates after one year (e.g. Rutledge and McLendon 1996, WSDE 2003, as cited within Lapina and Carlson 2008). Seeds have been observed as viable for up to 5-7 years. Alaska needs more local research on seed viability, germination rates and timing, and seed transport (Galatowitsch 2007).

Monocultures and invasive speed

Invasion happens quickly. For example, 40% of shorelines and islands in Wisconsin were colonized in under 15 years (Barnes 1999, as cited in Lavergne and Molofsky 2004), and at 41 of 62 study sites, RCG cover of 75-100% was reached within 10 years after wetlands were restored by interrupting drainage lines to promote flooding (Mulhouse and Galatowitsch 2003, as cited in Lavergne and Molofsky 2004).

Habitat preferences and landscape invasibility

Wetland susceptibility

In addition to the invasiveness of RCG as a species, the invasibility of a landscape influences establishment. In general, wetlands are more susceptible to vegetation homogenization than upland environments for several reasons. Wetland species are often widespread with efficient dispersal mechanisms (Santamaria 2002, as cited in Price 2020), which leads to more homogenous plant communities relative to uplands (Qian and Guo 2010, as cited in Price 2020). In anthropogenically disturbed wetlands this often leads to invasive species becoming the widespread dominant; examples in North America are RCG, *Phragmites australis*, *Lythrum salicaria*, and *Typha glauca* (Galatowitsch et al. 1999, as cited in Price 2020). Because wetlands are landscape sinks, accepting debris and water from neighboring uplands, they are more susceptible to anthropogenic disturbances upgradient, potentially promoting species invasion (Price et al. 2020).

Disturbance and fragmentation

Disturbance and habitat fragmentation can prevent specialists (species that only survive within a narrow range of environmental conditions) from maintaining populations and dispersing their population, and instead generalists (species able to thrive in wide variety of conditions) come to dominate landscapes. Fragmentation of habitat has been shown to increase species homogenization. Primary effects of anthropogenic changes to landscapes are hydrologic disturbance and nutrient enrichment, both of which favor RCG. A study of sites across the United States found that RCG was found in 58% of wetlands classified as “most disturbed,” 43% of “intermediately disturbed,” and 26% of “least disturbed” (Price et al. 2020).

Sedimentation and nutrient addition

A study in China found that RCG might take advantage of areas of increasing sedimentation by producing more ramets; consequently, wetlands with high sedimentation are more vulnerable to RCG invasion than wetlands with lower sedimentation rates. Overall, plants changed their growth habit (prostrate, vertical, detached; buds, rhizomes, ramets, biomass, propagule production) to the most adventitious strategy based on depth of burial (Chen et al. 2014). Another study in China found that exogenous nutrient addition caused an increase in RCG biomass accumulation, number of rhizomes, shoot mass ratio, and length of rhizomes and ramets. It concluded that wetlands with high nutrient enrichments of sediments may increase RCG invasion risk (Chen et al. 2017). In Wisconsin, a strong correlation was observed between agricultural areas and RCG-dominated wetlands, probably because of nutrient addition and sediment delivery from upslope sites to adjacent wetlands (Bernthal and Willis 2004). Another study in Wisconsin found that the most invaded ecosystem was emergent open-canopy wetland (Hatch and Bernthal 2008).

Soils

Reed canarygrass does particularly well in clay loam and sandy soils, but does not do well in peaty soils (Lyons 2014). In addition to thriving in wet habitats, RCG also grows along roadsides, in pastures, and in hay fields. Overall, RCG tolerates a variety of hydroperiods (see Maurer et al. 2003, as cited in Bernthal and Willis 2004) and favors canopy gaps.

Genetics and phenotypic plasticity

There is a tremendous amount of genetic and phenotypic variability in RCG. It is morphologically variable, with over 10 infraspecific categories (subspecies, varieties, races, and forms), and at least 11 cultivars (Lyons 2014). A laboratory study analyzing data from the Midwest examined 386 genotypes from 52 populations. This study indicates that RCG has high genetic diversity, mostly within populations, as opposed to among populations. Existing populations are a mixture of what have previously been distinct genetic groups (Nelson et al. 2014). Stands of RCG with purple and green panicles indicate a combination of genotypes (WRCGMWG 2009). This high variability makes RCG very adaptable and makes it difficult to predict where it may establish and how it will impact ecosystems.

Some genotypes are unpalatable to wildlife and livestock because of high alkaloid concentration, which increase with plant maturity (Starns 2014). However, cultivars have been developed specifically as a forage crop. Other cultivars have been selected for drought tolerance (Lyons 2014). In Wisconsin, RCG has been observed forming stands that are shade tolerant and on mesic to dry sites (upland oak savanna) and was still able to produce highly competitive monotypic stands (Henderson 1991, as cited in Lyons 2014).

Invasive genotypes differ from native populations in that they have greater biomass, more tillers, earlier emergence, and a wider range of carbon to nitrogen (C:N) ratios, that are on average 12% greater than native genotypes (see Lavergne and Molofsky 2007, Eppinga et al. 2011, as cited within Kaproth et al. 2013). Genotypes have high plasticity in their responses to leaf litter (Kaproth et al. 2013). Genetic diversity likely contributes to the invasiveness of RCG, by increasing phenotypic plasticity and adaptation to a variety of environments. For more on genetics, see Martina and von Ende 2012.

Ecological impacts

Biotic impacts

Numerous studies have looked at the impacts of RCG on other organisms. In general, it is known to have negative impacts on plant communities and fish, but inconclusive or mixed impacts on insects, arthropods, birds, mammals, and trees.

Wetland plants

Reed canarygrass outcompetes native vegetation. A study of urban wetlands in Portland, Oregon, found that RCG dominance reduced native plant diversity, canopy height, and canopy complexity (Weilhoefer et al. 2017). A study in Illinois found that plant diversity declined where RCG was dominant (Spyreas et al. 2010). A number of other researchers have noted that RCG reduces plant biodiversity (e.g. Silver and Eyestone 2012). A comparison of study sites across the United States found that RCG has the greatest impact on vegetation beta-diversity (the ratio between regional and local species diversity) in disturbed wetlands (Price et al. 2020). A study in Wisconsin showed that RCG crowds out seedlings, which can inhibit tree regeneration in riparian forests (WRCGMWG 2009).

In Alaska, the locally rare orchid *Cypripedium parviflorum* var. *pubescens* is only known from five sites, all within the Tongass National Forest. Reed canarygrass is the most notable invasive species that frequently co-occurs with this rare native species; RCG overtops this orchid and may threaten its long-term persistence (Carlson and Fulkerson 2017).

While most species are easily displaced by RCG, studies have found a few that can successfully live within an infestation. In the Pacific Northwest these include *Eleocharis palustris*, *Typha latifolia*, *Veronica scutellata*, and *Carex aperta* (Tu 2004). Research from Wisconsin and Minnesota have indicated that when carbon enrichment causes reduction in soil nutrients (specifically nitrogen), a native sedge (*Carex hystericina*) can competitively reduce RCG growth (Tu 2004).

Fish

Snyder (1992) suggests that RCG is used for cover and food by fish; however, this is contradicted by all other studies, which typically say that dense stands of RCG physically block salmon migration (e.g. Lantz 2000, Whatcom Weeds 2003, as cited in Lapina and Carlson 2008). Silver and Eyestone (2012) also note that RCG potentially reduces juvenile fish access to refuge and rearing habitats (e.g. side channels, tributaries and wetlands).

Insects

Studies indicate that stands of RCG hosted fewer insect trophic groups, and higher numbers of invasive insects, relative to native wetlands (Beaulieu and Wheeler 2002, Lavergne and Molofsky 2004, as cited in Spyreas et al. 2010). A study in Illinois found that Homopteran insects declined in diversity and abundance where RCG was dominant (Spyreas et al. 2010). In general, monospecific stands of vegetation reduce diversity of insects (Hansen and Castelle 1999, as cited in Lavergne and Molofsky 2004).

Arthropods

A study in Illinois found inconsistent effects on abundance and richness of arthropods where RCG was dominant (Spyreas et al. 2010). Another study of urban wetlands in Portland, Oregon, found there were distinct differences in arthropod communities in RCG and non-RCG dominated sites; however, canopy complexity and soil characteristics were primary factors affecting arthropods, rather than simple RCG presence, therefore RCG impacts on arthropods are indirect (Weilhoefer et al. 2017).

Birds

Snyder (1992) suggests that RCG is used for cover and food by waterfowl and upland game birds; Lyons (1998) contradicts this in saying RCG grows too densely to provide cover (as cited in Lapina and Carlson 2008). A study in Illinois found no relationship between richness or abundance of birds where RCG was dominant (Spyreas et al. 2010).

Mammals

Snyder (1992) suggests that RCG is used for cover and food by riparian mammals; Lyons (1998) contradicts this in saying RCG grows too densely to provide cover (as cited in Lapina and Carlson 2008). A study in Illinois found no relationship between richness or abundance of small mammals where RCG was dominant. However, in RCG dominated plots, mice were less abundant, while voles and shrews were more abundant (Spyreas et al. 2010). In humans, RCG can be a nuisance by causing allergies and hay fever when flowering (AKNHP 2011).

Abiotic

Physical and structural

Established RCG invasions may impact the physical and structural components of the ecosystem in the following ways:

- Increased deposition and sedimentation in waterways
- Changes to soil structure, soil hydrology, and soil content
- Reduced landscape heterogeneity and microtopography
- Decreased water velocity and altered hydrology
- Creation of thick sod and litter layer

Dense mats of rhizomes and stems trap sediment (Miller et al. 2008, as cited in Silver and Eyestone 2012) and increase silt deposition, causing constriction of irrigation canals and waterways (Lyons 1998, as cited in Lapina and Carlson 2008), and causing filling of riverine side channels and wetlands (Silver and Eyestone 2012). Reed canarygrass decreases velocity of water flow by creating more decomposing plant material (Miller et al. 2008, as cited in Silver and Eyestone 2012). It can also cause the opposite effect of increasing erosion where it grows perched on the edge of an incised waterway, because the relatively loose soil beneath the sod layer will cut away (Lyons 2014).

In addition to causing sediment deposition, RCG also decreases soil organic content and microstructure, and alters soil hydrology, which in turn reduces landscape microtopography and heterogeneity (Lyons 1998, as cited in Lapina and Carlson 2008; Werner and Zedler 2002, as cited in Lavergne and Molofsky 2004). Rhizomes, stems, and leaves can create a layer of sod one half meter thick (Tu 2004).
RCG outcompetes many native species in wet areas and creates conditions that favor its own growth. A study in Portland, Oregon, found that RCG dominance increased soil moisture and decreased soil organic content (Weilhoefer et al. 2017). In saturated soils (compared to dry soils), tillers initially produce faster, produce more growth, increase in radial growth, and increase the tillering distance from the parent plant (Martina and von Ende 2013). A study in China found that RCG burial had little impact on propagation and growth, indicating tolerance to burial and ability to thrive in wetlands with high sedimentation rates. Tolerance to sedimentation is correlated with nutrient enrichment. The study concludes that wetlands with high nutrient enrichments of sediments may increase RCG invasion risk. In this study, 100% of RCG plants survived, regardless of nutrient level or burial depth (Chen et al. 2017).

Chemical

Established RCG invasions may impact chemical components of an ecosystem in the following ways:

- Decreased dissolved oxygen
- Increased water temperature
- Alteration of nutrient cycling

Reed canarygrass increases water temperature (Lantz 2000, Whatcom Weeds 2003, as cited in Lapina and Carlson 2008) and decreases dissolved oxygen by slowing water flow and creating more decomposing plant material (Miller et al. 2008, as cited in Silver and Eyestone 2012).

Some research suggests that RCG potentially impacts nutrient cycling (Silver and Eyestone 2012) by decreasing retention time of carbon and nutrients in wetlands, reducing carbon sequestration capacity, and accelerating turnover (WRCGMWG 2009).

By contrast, other research suggests that invasive RCG genotypes have a higher C:N ratio relative to native genotypes and species. This high C:N ratio causes slower decomposition and consequently slower nutrient cycling. In turn, this leads to a thick litter layer and potentially suppression of native species. A large amount of litter stimulates growth for genotypes with high foliar C:N content, and this creates a positive feedback loop, in which a plant that creates large litter accumulations benefits from conditions with high litter (Kaproth et al. 2013). Native plants with a lower C:N ratio decompose faster, causing a thin litter layer and high nutrient availability.

A study of RCG infestations in Wisconsin found that these sites maintained higher rates of nitrification, suggesting RCG can make nitrogen more available and create positive feedback for its own growth. This may also indicate that RCG can decrease floodplain nitrogen storage and subsequent downstream nitrogen transport into coastal areas (Swanson et al. 2017).

Control methods and management strategies

No studies specific to control of RCG in Alaska were found in the literature review. The control and management methodologies used in other studies may provide a basis for duplicating studies locally. Findings from outside Alaska may be applicable within the state, but more research is needed.

The RCG Management Guide compiled by the Wisconsin Reed Canary Grass Management Working Group (2009) is a particularly useful resource to help land managers choose control strategies based on specific site characteristics.

Manual

Digging

For small infestations, RCG plants may be manually removed by digging, then collected and disposed. However, there are several concerns which detract from the effectiveness of manual removal techniques. First, manual removal is very labor intensive and therefore can be time consuming and expensive. Second, as RCG is known for extensive rhizome development below the soil surface, significant amounts of careful digging are required to avoid leaving any rhizome fragments behind. Large masses of soil must be collected, and this raises issues for hauling and disposal from remote locations. Third, special care must be taken to clip and collect any inflorescences before digging begins, as digging may inadvertently spread RCG seeds. Fourth, there is evidence from the Kenai Peninsula that RCG produces seeds that may remain viable for several years (perhaps 5-7 years or longer). Thus, even if all aboveground and belowground biomass are successfully removed in a manual effort, there could remain a significant bank of viable seeds ready to germinate. Manual removal efforts are most effective in combination with close observation and several years of repeated treatments.

Anderson (2012) suggests that if digging is used as a management strategy, it should be repeated 2-3 times per year for 5 years.

Seed removal

Seed head clipping is labor and time intensive but can assist in reducing the timeline for treatment of a particular area (similar to mowing, see below). Because RCG seed can remain viable for up to 7 years (Galatowitsch 2007), it's important to reduce the number of seeds that are allowed to mature. This treatment tactic should be used in conjunction with other treatment strategies, such as late season herbicide application.

Smothering

Reed canarygrass typically requires significant sunlight to germinate and establish. The smothering technique aims to take away RCG's access to sunlight. There are a couple of ways to accomplish covering that have been explored on the Kenai Peninsula, Alaska, such as cardboard overlain with wood mulch, and black poly overlain with road fabric. Covering may be effective if left in place and maintained for several years. However, there are several possible disadvantages of covering as a technique for eradication. First, covering is both labor and material intensive (although materials may be reused if maintained well), therefore costs may make this technique unsuitable for large infestations. Second, covering is intrusive and must remain in place for several years. It may not be suitable for areas where aesthetics and/or public access are a concern.

Outside Alaska, control by smothering has been successful. For example, a project in the Puget Sound region used several layers of cardboard under 4-6 inches of mulch, rather than weed barrier plastic/fabric (Tu 2004). Elsewhere successful control has been achieved using thick woven plastic fabric (Mirafi® or Amoco® brands), held in place for over one year, even during inundation. Fabric can be held in place with duck-bill tree anchors or 7-inch gutter spikes and washers. This method requires revegetation or reseeding after treatment (Tu 2004).

Mechanical

Mowing

Mowing can reduce aboveground biomass prior to tarping, digging, or herbicide application, to make these control methods easier to carry out. Mowing can also be used on a regular basis to keep a population in check by preventing seed development, and consequently propagation by seed. This control method needs to take place before RCG seeds mature, otherwise mowing will contribute to seed spread.

Research elsewhere indicates that mowing 1-2 times per years stimulates growth, while mowing 5+ times per year for 5-10 years is effective, although it hasn't been successfully applied on a large scale in the Pacific Northwest (Tu 2004). Anderson (2012) states that mowing in early spring and late fall has been shown to increase natives and reduce density of RCG, while mowing 5 times a year may provide even better control. Lyons (2014) supports this technique, citing evidence that cutting 5 times in one season removed RCG where it was growing in equal proportion to Kentucky bluegrass, timothy, and clovers. Frequent mowing is likely effective, in part, because it exposes ground to sunlight, which can promote the growth of native species (Anderson 2012). Tu (2004) suggests mowing for several years to deplete the seed bank, then mow and apply herbicides, usually after grass reaches 1-2 feet in height.

Chemical

Ecosystem considerations

Herbicide labels should always be carefully read and followed; the label is the law. The effectiveness of chemical applications can vary based on the type of ecosystem. For example, herbicides are generally more effective in upland, drier areas; one experiment showed the upper area of a canal ditch achieved 100% control while the lower area of the same ditch achieved 50% control (Hodgson 1968, as cited in Lyons 2014). Bruns (1973) also found spraying along the waterline was less effective due to dilution and removal of the herbicide from the soil by water (as cited in Lyons 2014). In southcentral Alaska, infestations are often mixed with native *Calamagrostis canadensis*, so treating RCG with grass-selective herbicides do not provide any advantage over non-selective herbicides (Galatowitsch 2007).

Timing

Some research indicates that chemical treatment should take place before RCG flowers, as seed production is not inhibited by chemical treatment (King Country 2011, as cited in Silver and Eyestone 2012). However, other research indicates that late fall application is most effective, with the second-best option being mid-summer just before summer dormant period (Tu 2004). If flowers or seeds are present, they should all be clipped before herbicide application (Silver and Eyestone 2012). If using herbicide after cutting, allow RCG to reach a height of 1-2 feet for better spray coverage (Tu 2004). In Alaska, mid-summer glyphosate treatments have not been very effective; late August to September glyphosate applications have had the best results (T. Stallard, personal communication, 2019).

Techniques to avoid off-target impacts

To avoid off-target impacts in wetlands, lift stems out of the water and push them over the clump to be sprayed. Clumps interspersed with native plants can be gathered, bundled, and sprayed to avoid off-target application. Any loose stem fragments in a water body should be manually removed (Silver and Eyestone 2012).

Herbicide regulation

The Alaska Department of Environmental Conservation (ADEC) regulates herbicide application through the Pesticide Control Program and issues pesticide use permits in accordance with 18 AAC 90.300. Application near water is strictly regulated and few herbicides are approved for use near water. Some permits may allow wiper applications of herbicide up to the water's edge, otherwise an aquatic use pesticide permit must be obtained prior to any application adjacent to or in water. The ADEC also regulates which pesticides are allowed in the state, and not all herbicides listed below are currently approved for use in Alaska.

Glyphosate

RoundUp Custom (glyphosate) is a non-selective, inexpensive herbicide that has been highly effective in Alaska when applied to RCG from late August through early October. It breaks down relatively quickly in the soil, binds to soil particles, and becomes biologically inert. Its mode of action is to block production of amino acids in the plant, specifically the enzyme EPSP synthase. All plants have EPSP synthase which is a critical component of plant growth and function, but animals – including humans – do not produce EPSP synthase.

Other projects have had success with glyphosate, applied at 1.5-2% solution plus surfactant (e.g. Tu 2004, Silver and Eyestone 2012). In Washington, this concentration of glyphosate and surfactant has also been used successfully in conjunction with 1% imazapyr. Lyons (2014) suggests applying glyphosate in early spring when RCG begins to sprout and before other species germinate, or in the fall, at a rate of 1.2-2.5 pounds of active ingredient per acre.

By contrast, a study in Illinois used test plots to compare long term effectiveness of herbicides glyphosate and clethodim. Two years after treatment the glyphosate plot had returned to a RCG stand, while the clethodim was more successful (Mason 2020).

Clethodim

In the study by Mason (2020) the clethodim (selective herbicide) treatment took longer to show effects, and some RCG weakly resprouted, but suppression of the grasses allowed native sedges and forbs to increase in cover and vigor. Two years after treatment, the area recovered with native plants and the diversity of a sedge meadow. This herbicide is not approved for use in or near water.

Imazamox

There is limited data regarding the use of Imazamox on RCG. Recently, it has been used on the Swanson River Oil Fields in the Kenai National Wildlife Refuge. This herbicide provides some residual control.

Sethoxydim

Sethoxydim (e.g. Vantage) is a grass-specific herbicide that has been successfully used on RCG in the Pacific Northwest; however, it is not labeled for aquatic use (Tu 2004). Specifically, it has been somewhat successful where sedges are the dominant native species (Tu et al. 2001, as cited in Galatowitsch 2007).

A study in Wisconsin found Sethoxydim to be somewhat less successful. This study followed nine field experiments for three years. Sethoxydim prevented RCG from flowering, reduced cover to less than 40%, and reduced height by 50%. However, only 2 of 9 sites showed declines throughout the three-year experiment. Instead, RCG recovered each year in most treatment plots. Findings show RCG developed resistance to Sethoxydim and continued to have robust growth from seeds and rhizomes. Moreover, post-treatment seeding with native sedge meadow species was not successful. Four sites were on what had previously been agricultural land, and rather than successful seeding with natives, during the study non-natives increased in cover and species richness. By year four, three of the sites that had achieved native species coverage reverted to dominance by RCG (Healy and Zedler 2010). This suggests that prior land use plays a role in the success of treatment.

Fluazifop

Fluazifop (e.g. Fusilade, Horizon) is a grass-specific herbicide that has been somewhat successful where sedges are the dominant native; however, it is not approved for aquatic sites (Tu et al. 2001 in Galatowitsch 2007). It should be applied to actively growing grasses, not stressed grasses (William et al. 1997, in Lyons 2014). The recommended application rate is 0.25-0.375 pounds of active ingredient per acre (1 to 1.5 pints product per acre), plus 1% volume concentration (v/v) crop oil concentrate or 0.25% v/v nonionic surfactant (William et al. 1997 in Lyons 2014). It takes 2-4 weeks for results to become apparent with Fluazifop. If regrowth occurs, application should be repeated (William et al. 1997, in Lyons 2014).

Sulfometuron

Sulfometuron (e.g. Oust) can be applied as a preemergent or early postemergent treatment. The recommended application rate is 26-43 gallons of active ingredient per hectare (equivalent to 3 to 5 ounces of product per acre), plus 0.25% v/v nonionic surfactant for postemergent applications (Lyons 2014).

Cultural

Flood

Flooding is typically used in conjunction with tillage. Control of large infestations near Vancouver, Washington, and Corvallis, Oregon, have been successful using a combination of tillage and flooding to restore native wetlands from RCG infestations. However, this requires heavy equipment and ability to control water levels. It is recommended to till through sod as soon as it is dry enough in the spring, and it may require several passes. Allow exposed rhizomes and stems to dry out. Till several times throughout the summer to dry and breakup all rhizomes. Tilling is complete when there is nothing left but broken up clods of soil. Then keep the site under 18 inches of water until the following June. Follow-up with herbicide spot treatment for several years and use site-specific restoration techniques (Tu 2004).

Flooding without tillage may be successful but depends on being able to control water levels.

Fire

Burning alone is generally not effective but can be used in conjunction with other management strategies. For example, burning can be used as a pretreatment to herbicide, shade cloth, or tillage, because it will eliminate standing vegetation and dead litter (Tu 2004). Lyons (2014) suggests that controlled burning is best used in highly productive wetlands with a robust seed bank of fire-adapted natives. Studies have shown a 2-to-3-year burn rotation to be successful, but may be required for 5-6 years. Additionally, early burns can accelerate RCG spread, while late spring burns reduce stands. Late autumn burns are also helpful.

Grazing

There is mixed research on managing RCG through grazing. Some genotypes are unpalatable to wildlife and livestock because of high alkaloid concentrations, which increase with plant maturity (Starns 2014). However, cultivars have been developed specifically as a forage crop. Tu (2004) suggests that goats and sheep will graze on RCG but this is not an effective control method on its own; it can be used in place of mowing, and then followed by tillage, herbicide, and/or smothering. Also, grazing in wetlands likely damages the wetland and is hard to navigate for livestock, as they may get stuck in the mud. Additionally, herbivory may induce the plants' physical and chemical defenses, while mechanical cutting does not (Lyons 2014).

A syndrome known as 'Phalaris staggers' is caused by *Phalaris aquatica* (Rendell 2012) and may also be caused by some types of RCG (Lyons 2014). This syndrome is caused by plant alkaloids that can affect sheep and cattle, most commonly in fall and early winter. It impacts nerves responsible for swallowing, so may indirectly cause weight loss. In severe cases, it can also cause death by heart failure. Signs of Phalaris staggers include 'bunny hopping' with a wide gait, head nodding, and obvious inability to control tongue function. Another syndrome called 'Phalaris sudden death' may affect sheep and cattle and is most common in fall or early winter and is thought to result from a different compound in RCG which limits nitrogen metabolism and leads to ammonia poisoning (Rendell 2012).

Competitive planting

Competitive planting is most likely to be effective at excluding RCG in habitats that are marginal for RCG to begin with (Tu 2004). The basic principle behind this technique is that seed germination requires light penetration, so encouraging complex canopies within the herbaceous layer can help prevent RCG infestation (Tu 2004). Shading by planting trees and shrubs can also help reduce RCG (Anderson 2012).

A 2-year study in Washington compared willow staking at various spacings along a sloping edge of a wetland dominated by RCG. Willows successfully reduced RCG biomass with best results found from planting willows at 2-foot centers (equivalent to planting density of 0.6 meters). This reduced RCG average biomass in the first season by 44.9% and the second season by 68%. The second-most effective treatment was planting at 3-foot centers (density of 0.91 meters), achieving 56.1% reduction in the second year. Willow growth was somewhat suppressed in wetter areas of the study site, perhaps due to RCG growing more competitively in wetter soils. However, increased RCG competition in wetter sites may not be strong enough to counteract willow's long term shading impact. Additionally, willow leaf shading may decrease in drier areas, indicating that RCG becomes more competitive against willows in drier sites. Overall, this study found that competition is moisture dependent, and shading is likely the primary – but not only – variable affecting willow-RCG interactions (Kim et al. 2006).

The City of Portland Bureau of Environmental Services has had success with planting high-density cottonwood or alder. Where a closed canopy was reached by year five, they reported near eradication of RCG. In a forested wetland dominated by conifers, it is recommended to cut large holes in fallen dead trees and plant saplings in these holes. If planting directly into an infested wetland, keep RCG mowed until planted trees and shrubs establish, or plant on top of soil mounds (Tu 2004). The Portland Bureau of Environmental Services also suggests that the transitional zone between emergent and upland areas is the most difficult to treat. They recommend 1) staking of willow and dogwood, and 2) scalp off sod patches about 5x3 feet in area, then plant about 10 shrub starts in the scalped area and mulch well (Tu 2004).

Some graminoids and forbs may also be suitable for competitive planting and/or revegetation. In the Willamette Valley, these include *Beckmannia syzigachne, Eleocharis palustris, Carex densa, C. feta, C. unilateris, Juncus oxymeris, Deschampsia caespitosa, Agrostis exarata, Myosotis laxa, Plagiobothrys figuratus,* and *Veronica scutellata* (Tu 2004). Many of these are also common and native in Alaska, but it is best to cross check this list with regional native flora first.

Lastly, encouraging microtopographies in wetlands through prevention of sediment accumulation improves native species richness (Tu 2004). In other words, creating an uneven ground surface can promote competition with native species. Additionally, sawdust can be applied around desirable plants to suppress RCG by removing excess nitrogen (Anderson 2012).

Biological

Currently there are no biological controls approved for use in Alaska. The literature review did not turn up any biocontrol options for RCG in North America, other than cultural options with livestock mentioned above.

Remote mapping

Remote mapping methodologies have been used in other states and may be adapted for use in Alaska. The Wisconsin Department of Natural Resources developed a landscape scale method of monitoring wetland vegetation composition. A pilot project used Landsat 7 satellite imagery (30-meter pixel resolution) to map and classify coverage and extent of RCG across 737,454 acres of wetlands (Bernthal and Willis 2004). Given RCG senesces much later in the fall than native species, it is possible to map RCG's unique spectral signature from imagery captured in mid-October. Bernthal and Willis developed an inexpensive and feasible classification protocol for RCG-dominated wetlands (greater than 80% coverage of RCG), with accuracies reliable and compatible to a minimum mapping scale of 0.5 acres. While the 'heavily dominated by RCG' category was 86% accurate, other vegetation categories were much less reliable (i.e. forests, shrubs, water-dominated wetlands) due to the spectral signatures of woody debris and water interfering with the classification. Bernthal and Willis' protocol is highly reliable for statewide assessment of open canopy emergent wetlands where RCG is the dominate grass. The Normalized Difference Vegetation Index was not needed for classification, and images from multiple years between 1999-2003 were used.

In 2008 Hatch and Bernthal expanded the mapping and classification method to the entire state of Wisconsin, focused only on wetland habitat. Two categories of vegetation cover were defined within these wetlands: 1) greater than 50% cover of RCG by visual estimate, and 2) less than 50% cover of RCG. Of the 5,065,419 acres of Wisconsin's wetlands that were analyzed using Landsat 7 & 5 satellite imagery, 498,250 acres were classified as dominated by RCG. "We found classification of Landsat satellite imagery to be the most cost-effective method to broadly capture the impact reed canarygrass has on our native wetland plant communities." Field sites that were easy to access and homogenous landcover were chosen for ground truthing the satellite data. Ground-truth data was used to both train the classification and assess accuracy. Reed canarygrass dominated (> 50% occupied) 26% of Wisconsin's emergent, open canopy wetlands. Authors proposed re-classifying every 5-10 years to detect plant cover changes over time. Overall accuracy was determined to be 61-83%, while the user's accuracy for reliability of classification of RCG-dominated wetlands was 72-92%. A statewide raster grid with a minimum mapping unit of 0.5 acres was produced, and pixels were classified into "three possible values: 0 = unclassified (upland or clouds); 1 = <50% RCG cover; 2 = > 50% RCG cover." "A close-up analysis of the output raster grid revealed some possible sources for errors of commission, such as heavily grazed pasture fields being falsely classified as reed canarygrass. Cranberry bogs also maintained green leaves on bushes after mid-October and could have been misclassified." This method is not reliable for classification within forest and shrub vegetation, nor for areas smaller than 0.5 acres that are not dominated by RCG (Hatch and Bernthal 2008).

Infestations of RCG are not dense enough throughout most of the Kenai Peninsula to apply the Bernthal and Willis (2004) nor Hatch and Bernthal (2008) remote sensing classification methods to the peninsula at this time. Rather, it is thought that remote sensing options captured at higher resolution (i.e. imagery collected via fixed wing airplane) during October could be further investigated, followed by the creation of a supervised classification method that could capture new infestations of RCG as they expand in population but have yet to dominate the landscape.

Data Gaps

The literature review indicates a lack of Alaska-specific research. Most data sources originated out of state, therefore applicability in Alaska is limited, given the state's unique climate and ecosystems. However, the referenced literature contains methodologies for research that can be applied in Alaska, avoiding the need to reinvent the wheel with both controlled experiments and observational studies. Some specific areas recommended for Alaskan study are herbicide trials; correlations with biota diversity and abundance; seed viability, germination rates, timing, and spread potential; impacts to sedimentation and hydrology; nutrient cycling (specifically in alder dominated riparian areas at headwater streams); and comparison of biotic and abiotic characteristics across sites dominated by either RCG or *Calamagrostis canadensis*. Additionally, there is no data for Alaska or elsewhere on the economic impacts caused by RCG, and this is greatly needed to develop management thresholds and quantify the benefits of invasive plant control.

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