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Russian-olive (*Elaeagnus angustifolia*) Biology and Ecology and its Potential to Invade Northern North American Riparian Ecosystems

Liana K. D. Collette and Jason Pither*

Russian-olive is a small tree or large multistemmed shrub that was introduced to Canada and the United States from Eurasia in the early 1900s. It was provisioned in large numbers during the last century to prairie farmers as a shelterbelt plant and remains a popular and widely available ornamental. Now invasive within some riparian ecosystems in the western United States, Russian-olive has been declared noxious in the states of Colorado and New Mexico. With traits including high shade tolerance and a symbiotic association with nitrogen-fixing bacteria, Russian-olive has the potential to dominate riparian vegetation and thus radically transform riparian ecosystems. Especially alarming is its capacity to influence nutrient dynamics within aquatic food webs. Our objective is to draw attention to Russian-olive as a potential threat to riparian ecosystems within Canada, especially in the southwest, where invasion is becoming commonplace. We review what is known about its biology and about the threats it poses to native organisms and ecosystems, and we summarize management and control efforts that are currently underway. We conclude by proposing a research agenda aimed at clarifying whether and how Russian-olive poses a threat to riparian ecosystems within western Canada.

Nomenclature: Russian-olive; *Elaeagnus angustifolia* L. ELGAN.

Key words: Dominance, Elaeagnaceae, exotic species, invasion biology, riparian ecosystems.

Russian-olive (*Elaeagnus angustifolia* L., Elaeagnaceae) is a small tree or large multistemmed shrub native to southern Europe and central and eastern Asia (Katz and Shafroth 2003; Little 1961). Introduced to Canada and the United States in the early 1900s for use as an ornamental, a shade plant, and a windbreak (Hansen 1901; Katz and Shafroth 2003), Russian-olive has since become invasive within riparian ecosystems throughout the western United States and parts of southern Canada. It can have detrimental ecological impacts (Katz and Shafroth 2003), especially in riparian ecosystems, and consequently has been declared noxious in the states of Colorado and New Mexico (Bean et al. 2008). It also is listed as potentially invasive and banned in Connecticut (Bean et al. 2008). By contrast, a federally funded program sponsored the planting of Russian-olive plants throughout the Canadian prairies from 1948 until as recently as 2002 because it was a valued shelterbelt tree/shrub that aided in the conservation of prairie soils. Russian-olive continues to be sold as an ornamental throughout Canada.

Our objective is to call attention to Russian-olive as an emerging exotic invasive plant within western Canada and to highlight questions that urgently need answering if we are to prevent our riparian ecosystems from resembling those invaded by Russian-olive in the western United States. We begin by reviewing the biology of Russian-olive and describe what is known about its history within North America. Contributing to the latter are novel maps illustrating the numerical and geographical scope of the prairie shelterbelt planting program within Canada. Next, we describe what little is known about the current distribution and potential for invasion of Russian-olive in western Canada. We then review research concerning the ecological impacts that Russian-olive can have, focusing especially on riparian ecosystems, and then shift toward management implications, describing control efforts that are currently underway. We conclude by presenting a

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* Graduate student and Assistant Professor, respectively, Biodiversity and Landscape Ecology Research Facility and The Okanagan Institute for Biodiversity, Resilience, and Ecosystem Services, University of British Columbia, Okanagan Campus, ASC367-3187 University Way, Kelowna, BC V1V 1V7, Canada. Corresponding author's E-mail: liana.collette@gmail.com; jason.pither@ubc.ca

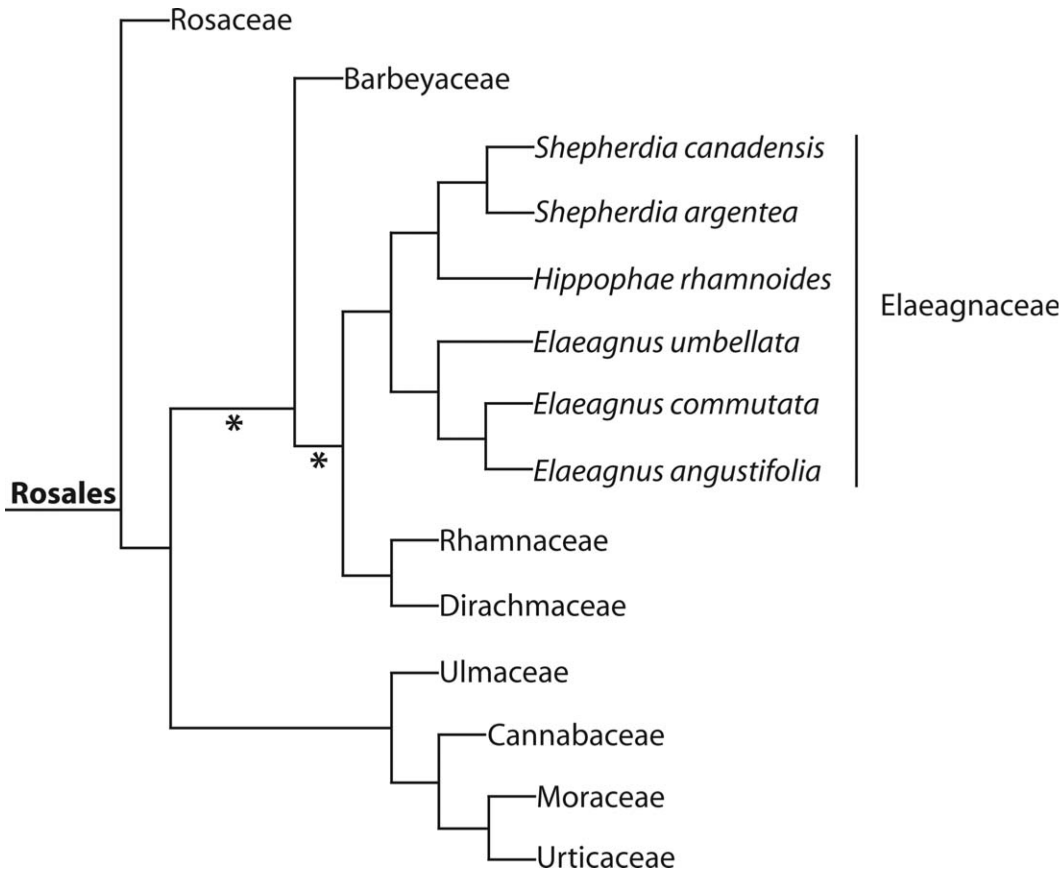

Figure 1. Phylogenetic tree of the order Rosales. Asterisks (*) denote branches with < 50% support, all other branches have > 80% support. Figure adapted from Stevens (2013).

research agenda aimed at clarifying if and how Russian-olive poses a threat to riparian ecosystems within western Canada.

We define the terms ''naturalization'' and ''invasion'' following Richardson et al. (2000), where naturalization occurs when an introduced species forms self-sustaining populations close to the site of introduction without human intervention, whereas invasion occurs when the species produces reproductive offspring far from the site of introduction (> 100 m over < 50 yr for seed propagated plants and > 6 m over 3 yr for plants propagated by root, rhizomes, stolons, or creeping stems).

Russian-Olive Biology

Taxonomy. Phylogenetically, Russian-olive remains enigmatic; its position within the angiosperms is not entirely resolved (Bartish 2002; Zhang et al. 2011), in part because the systematics of the family to which it belongs, the Elaeagnaceae, is itself uncertain. The most likely placement of the family has only 50% support in recent phylogenetic analyses (Hilu et al. 2003; Savolainen et al. 2000; Soltis et al. 2000; Stevens 2013; Sytsma et al. 2002) (Figure 1). Both native and nonnative confamilial species of Russian-olive occur in Canada and typically share the same habitat requirements as Russian-olive (Table 1). The native species include *Elaeagnus commutata* Bernh. ex Rydb. (wolf-willow), *Shepherdia canadensis* (L.) Nutt. (soopolallie or buffaloberry) and *Shepherdia argentea* (Pursh) Nutt. (thorny buffaloberry), and two nonnative comfamilials, *Hippophae rhamnoides* L. (sea-buckthorn) and *Elaeagnus umbellata* Thunb. (autumn olive). Like Russian-olive, the latter two species were intentionally introduced to Canada in the early to mid-1900s (Catling et al. 1997; Li and Schroeder 1996; Oliver 2001). Superficially, *E. commutata* and Russian-olive appear similar in the field owing to their silvery grey leaves, but the latter species is distinguished by the reddish, sometimes shredding bark and sharp thorns that arm its branches. The other confamilial species show little resemblance to Russian-olive.

Phenology. Although phenology will vary throughout its introduced North American range (as it does within British Columbia (BC); Collette and Pither, unpublished data), bud break generally occurs in early spring, with flowering among mature trees commencing in mid to late spring.

Table 1. Ecozones, natural habitats, and habitat requirements of Russian-olive and its confamilials in Canada. Information adapted from Esser (1995), Li and Schroeder (1996), the Evergreen Native Plant Database (2013) and Muma (2013).

Species	Common name	Ecozone	Natural habitat	Moisture requirement	Light requirement	Soil requirement
Elaeagnus angustifolia	Russian-olive	Atlantic Maritime Mixedwood Plains Prairies Montane Cordillera	Forest edge Prairie/meadow/field Wet meadow/prairie/field Riparian (edge) Desert Lakeshores	Dry Normal Moist	Sun Partial shade	Clay Sand Calcic
Elaeagnus commutata[a]	Wolf-willow Silverberry	Boreal Shield Prairies Montane Cordillera Hudson Plains	Forest edge Prairie/meadow/field Riparian (edge) Lakeshores	Dry	Sun Partial shade	Clay Sand
Shepherdia canadensis[a]	Soopolallie Silver buffaloberry	Taiga Plains Taiga Shield Boreal Shield Atlantic Maritime Mixedwood Plains Boreal Plains Prairies Taiga Cordillera Boreal Cordillera Pacific Maritime Montane Cordillera Hudson Plains	Woodland (35–60% cover) Forest edge Riparian (edge) Swamp/marsh (nutrient rich) Rocky bluff Lakeshores	Dry Normal Moist	Sun Partial shade	Clay Sand Loam Calcic
Shepherdia argented[a]	Thorny buffaloberry	Prairies	Woodland (35–60% cover) Salt water shorelines	Dry Normal Moist	Sun	Sand Loam Clay
Hippophae rhamnoides	Sea buckthorn	Boreal Shield Prairies	Open areas Riverbanks Seashores	Dry Normal Moist	Sun	Sand Loam
Elaeagnus umbellata	Autumn olive	Atlantic Maritime Boreal Shield Mixedwood Plains	Forest edge Fields and open areas	Dry Normal	Sun	Clay Sand

[a] Species native to Canada.

The flowers are yellow and fragrant and are pollinated by insects (Katz and Shafroth 2003; Pendleton et al. 2011). In late summer, the pollinated flowers mature into clusters of oval-shaped, 1- to 1.5-cm-long fruits, each containing a single seed (Lesica and Miles 2001; Young and Young 1992). Fruit dispersal happens during the fall and winter, primarily through consumption and dispersal by birds (Borell 1962; Kindschy 1998; Olson and Knopf 1986) and mammals (Kindschy 1998), and potentially through fluvial transport (Brock 1998; Pearce and Smith 2001).

Natural Enemies. In its native range, Russian-olive is attacked by several fungi species; multiple insect species from the orders Coleoptera, Hemiptera, and Lepidoptera; and mite species from the families Tetranychidae and Eriophyoidae (CABI 2009; Zheng et al. 2006). A moth, *Teia prisca* (Staudinger) (Lepidoptera: Lymantriidae), is believed to be a specialist on Russian-olive (Zheng et al. 2006). Surveys for a biocontrol agent in Russian-olive's native range indicate herbivores attack the trunk, inner bark, shoots (young and old), leaves, flowers, and fruits (CABI 2009). One particular fungus inhabiting Russian-olive's native range, *Phomopsis elaeagni* Sandu (Diaporthaceae), causes cankers in the branches and stems of Russian-olive and is responsible for large-scale dieback of Russian-olive stands in the United States and Canada (Arnold and Straby 1973; James 1983).

Important Ecological Traits. On the basis of research conducted in the United States, Russian-olive appears to be

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shade tolerant compared with co-occurring native species, such as cottonwood (*Populus* spp., Salicaceae) and willow (*Salix* spp., Salicaceae), and this may facilitate its dominance in the understory of habitats primarily composed of these pioneer species (Reynolds and Cooper 2010). Moreover, whereas cottonwood and willow seed germination requires flooding and high-light conditions, Russian-olive will germinate in shadier, drier conditions (Reynolds and Cooper 2010; Shafroth et al. 1995), even under full canopies (Katz and Shafroth 2003). Furthermore, owing to a symbiosis with nitrogen-fixing actinomycetes of the genus *Frankia* (Huss-Danell 1997; Miller and Baker 1985), Russian-olive can establish on bare, mineral substrates that are unfavorable for species lacking such symbioses (Shafroth et al. 1995). Russian-olive can also form associations with vesicular–arbuscular mycorrhizae (Riffle 1977), and this too may provide a competitive edge. Because Russian-olive seeds are much larger than seeds of native cottonwoods (*Populus* spp.) (roughly 4 times heavier and 3.3 times longer than *Populus deltoides* W. Bartram ex Marshall seeds; Young and Young 1992) (Shafroth et al. 1995), Russian-olive seeds could have an establishment advantage in both disturbed and undisturbed areas (Katz et al. 2001; Lesica and Miles 1999; Shafroth et al. 1995).

Recently, Nagler et al. (2011) outlined several different factors that promote the present distribution and abundance of Russian-olive in the United States. These include (1) a chilling requirement, potentially needed for bud break and seed germination (Friedman et al. 2005; Guilbault et al. 2012); (2) supplemental moisture in arid and semiarid regions, which is often provided in riparian areas, floodplains, reservoir margins, and canals; (3) increased river flow regulation leading to less flooding and less disturbance, conditions that are unfavorable for native plant seedling establishment (i.e., cottonwoods and willows); (4) silt loam and silty clay soil types, which occur between terrestrial and aquatic habitats (Madurapperuma et al. 2013); and (5) high soil salinity and alkalinity conditions, in which Russian-olive is more tolerant than native species (Nagler et al. 2011).

Russian-Olive Distribution: Past and Present

Historical Plantings and Canada's Prairie Shelterbelt Program. Russian-olive's dense growth form, relatively large seeds, and ability to tolerate colder climates (Friedman et al. 2005; Gusta et al. 1983) and a wide range of soil and moisture conditions (Lesica and Miles 2001; Reynolds and Cooper 2010) made it an ideal shelterbelt plant across the prairie provinces and states (Olson and Knopf 1986). From 1901 to spring 2013, the Government of Canada's (Prairie Farm Rehabilitation Administration [PFRA]) Prairie Shelterbelt Program (discontinued as of 2013) provided shelterbelt tree and shrub seedlings, including Russian-olive, to eligible agricultural lands in Manitoba, Saskatchewan, Alberta, and the Peace River region of British Columbia. The Prairie Shelterbelt Program in conjunction with another PFRA program, the Community Pasture Program, aimed to minimize the effects of drought by protecting and managing native prairie land and water resources (Marchildon 2009). The program administrators kept a database of planting records detailing the plant species, location, year, and amount distributed since its inception. We obtained program planting records for Russian-olive from the current administrators, Agriculture and Agri-Food Canada. We assumed that all plants distributed through this program were planted and therefore refer to these records as planting data. The planting locations were stored in the Dominion Land Survey format. Using open source Dominion Land Survey grids (GeoGratis, http://geogratis.gc.ca/api/en/nrcan-rncan/ess-sst/f907a02c-f592-5261-ab4e-4bdae67a73ad.html) and ArcGIS 10.1 (Environmental Systems Research Institute 2012), we mapped the plantings to section. Here, we define a planting as a section of land (1 mi^2 or $\sim$ 2.60 km^2) in which multiple Russian-olive seedlings have been planted. These data contained 3,395 of 3,777 plantings, or 90% of plantings, with known locations.

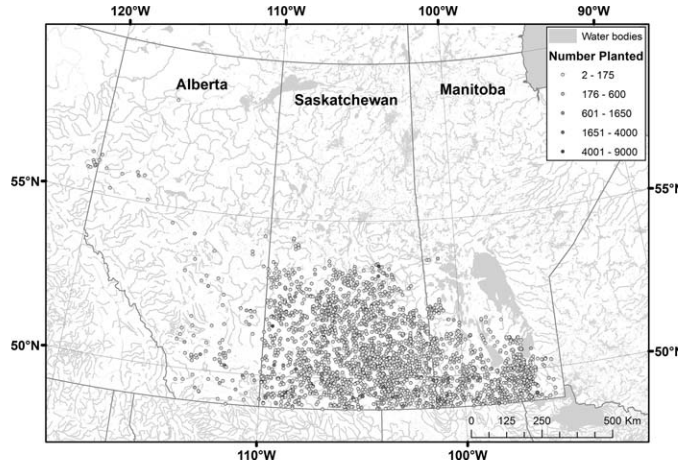

Figure 2. Number of Russian-olive seedlings planted through the Prairie Shelterbelt Program. North American Datum of 1983, Canadian Spatial Reference System, Universal Transverse Mercator Zone 13N projection.

From 1948 to 2002, a total of 1,086,654 Russian-olives were planted. Of the records with locations provided, the majority of Russian-olive seedlings occurred in Saskatchewan (335,945 plants), followed by Manitoba (98,368 plants), Alberta (17,975 plants), then British Columbia (975 plants) (Figure 2). According to Moore (1964), Canadian shelterbelt plantings of Russian-olive were apparently not nearly as extensive as those in the United States.

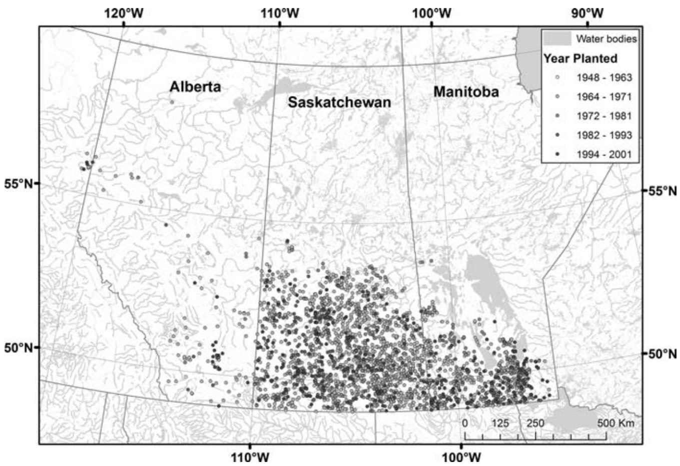

Figure 3. The years in which Russian-olive was planted through the Prairie Shelterbelt Program. Projection as in Figure 2.

Most of the prairie plantings occurred between approximately 1968 and 1974, and again between 1988 and 2000 (Figures 3 and 4a). The years 1969 and 2002 included particularly high numbers of plantings (Figure 4b). We could not find any evidence of plantings beyond the year 2002.

Invasive Distribution and Occurrence Records. In its native range, Russian-olive is found primarily along coasts and riparian areas and spans a broad temperature range (Katz and Shafroth 2003). Similar patterns are emerging in its introduced, North American range. For example, Russian-olive has a characteristically patchy distribution throughout riparian habitats in western United States and has begun to invade riparian areas in western Canada (Jarnevich and Reynolds 2011; Nagler et al. 2011). In the United States, Russian-olive thrives in riparian areas where cottonwoods typically dominate (Knopf and Olson 1984; Lesica and Miles 1999). However, in southern Alberta, it can also be found near small creeks and wetland areas where woody vegetation is absent (A. McClay, McClay Ecoscience, and R. Bourchier, Agriculture and Agri-Food Canada [AAFC], personal communication). In BC, Russian-olive has been observed to occur naturally in dry habitats in close proximity to waterbodies, moist to dry roadsides, and the steppe zone (a large portion of the Bunchgrass Biogeoclimatic Ecosystem Classification zone) (Douglas et al. 1999). Preliminary surveys conducted by L.K.D.C. indicate that it commonly co-occurs with willows (*Salix* spp.), cottonwoods (*Populus* spp.), sagebrush (*Artemisia* spp., Asteraceae), Saskatoon (*Amelanchier alnifolia* Nutt., Rosaceae), and roses (*Rosa* spp., Rosaceae), although detailed data about Russian-olive densities await collection.

Despite its obvious prevalence along many rivers in southwestern Canada, official occurrence records are lacking. For instance, as of fall 2013, only a single record of Russian-olive had been entered into the Government of British Columbia's Invasive Alien Plant Program (IAPP) online application within the 8 yr since the IAPP was initiated (L. Kristiansen, BC Ministry of Forests, Lands, and Natural Resource Operations, personal communication). We suspect this is primarily due to a lack of awareness of its status as an exotic and potentially invasive species.

Russian-olive invasion is becoming increasingly evident in western Canada, although in most cases, the source for these populations is unknown. In regions that received shelterbelt plantings and that harbor favorable conditions for growth, program plants may have served as sources for invasion. Horticultural plantings may also serve as sources, as Russian-olive is a popular ornamental and remains available for purchase. Russian-olive invasion has been observed in southeastern Alberta, in the vicinity of the city

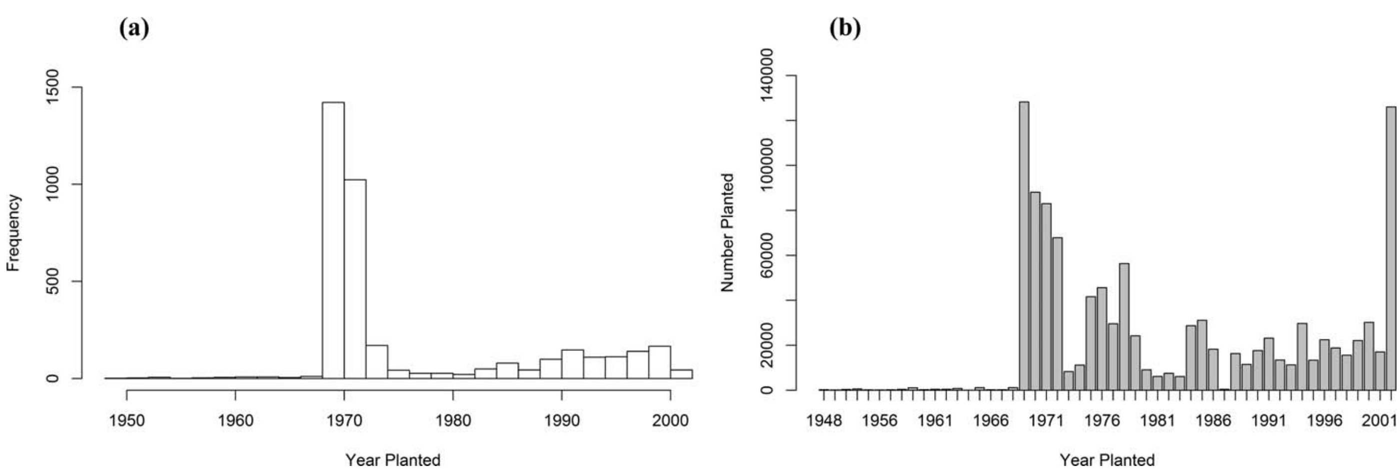

Figure 4. (a) Frequency of Russian-olive plantings across the Canadian prairies from 1948 to 2002. (b) Number of Russian-olive seedlings planted per year.

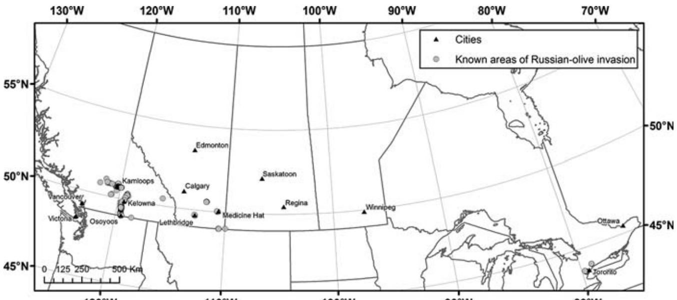

Figure 5. Areas of known Russian-olive invasion in Canada. Projection as in Figure 2.

of Medicine Hat (A. McClay, personal communication), for example (Figure 5). Whether its spread in this region originated from Prairie Shelterbelt Program plantings or horticultural plantings in residential areas is uncertain (D. Young, City of Medicine Hat, personal communication). A single planting of 25 seedlings was established in 1970 within the Medicine Hat city boundary. Within a 15-km radius outside of the city boundary, three program plantings, totaling 1,300 seedlings planted, were established between 1969 and 1970. Therefore, a total of 1,325 seedlings were planted in and within the vicinity of Medicine Hat, suggesting the program may have played a part in Russian-olive's spread, but more research is needed to assess this. Along the Old Man River in southern Alberta, Russian-olive is encroaching into the coulees from city backyard plantings (R. De Clerck-Floate, AAFC, personal communication) (Figure 5). Yet in central and northern Alberta, where Russian-olive is a popular ornamental, it has not shown any signs of escaping cultivation (A, McClay, personal communication). In southern BC, Russian-olive establishment is extensive along a 10-km portion of Highway 97 from Summerland to Osoyoos (L. Collette, personal observation) (Figure 5). Extensive invasion has also been observed along a 40-km reach of river upstream of Kamloops, BC, on the Thompson River, most likely originating from riverbank plantings 100 yr ago (Pearce and Smith 2009) (Figure 5). Russian-olive is also becoming invasive in eastern Canada, specifically in Toronto, ON (D. Battiste, personal communication) (Figure 5).

Pearce and Smith (2001) examined Russian-olive dispersal along the Milk River starting 40 km from the Alberta/Montana border and then extending 160 km into the United States. In 1950, Russian-olive was introduced to the Aageson Ranch in Montana, about 10 km downstream of the international border as a windbreak and for erosion control, however, there are no known plantings on the Alberta side of the border. The 2001 study by Pearce and Smith, in conjunction with another one of their studies (Pearce and Smith 2009), determined that Russian-olive density was considerably greater downstream of Aageson Ranch compared with the upstream reaches in southern Alberta. Approximately 48 Russian-olive plants (seedlings, saplings, and trees) were observed in the Canadian portion of the study, suggesting seeds were transported upstream by wildlife (Pearce and Smith 2001).

The potential distribution of Russian-olive in Canada is currently unknown, as previous models predicted its potential distribution primarily in the United States (Hoffman et al. 2008; Jarnevich and Reynolds 2011) and were not made using Canadian occurrences (Hoffman et al. 2008; Jarnevich and Reynolds 2011; Peterson et al. 2003). Furthermore, they did not include potentially important abiotic predictors of Russian-olive distribution, such as river regulation and soil characteristics (see above).

Ecological Impacts

Russian-olive's establishment within many U.S. riparian habitats has spurred a substantial amount of research and funding in the country over the past decade (Nagler et al. 2011), focused primarily on elucidating its potential effects. Findings include (1) lower bird species richness and diversity (Brown 1990; Knopf and Olson 1984) than in surrounding native plant species, (2) potential nesting habitat for the endangered southwestern willow flycatcher (*Empidonax traillii extimus* A. R. Phillips, Tyrannidae) (USDA 2012), and (3) significant nitrogen input to streams (Mineau et al. 2011) and soils (DeCant 2008; Follstad Shah et al. 2010). Reviews by Katz and Shafroth (2003), Shafroth et al. (2010), and Nagler et al. (2011) describe many additional examples of ecological effects; here, we highlight new findings from the United States that are especially relevant to riparian habitats and rivers in western Canada, where Russian-olive is gaining a foothold.

Several studies indicate Russian-olive invasion is drastically altering aquatic ecosystem functioning (e.g., Kominoski et al. 2013; Mineau et al. 2011, 2012). Streams invaded with Russian-olive are not as limited by nitrogen compared with uninvaded streams (Mineau et al. 2011). Furthermore, the primary limiting nutrient of some invaded streams has been observed to shift from nitrogen to phosphorus, perhaps due to Russian-olive's ability to fix nitrogen (Mineau et al. 2011). When coupled with anthropogenic sources of nitrogen from agriculture and urban–suburban areas where Russian-olive planting is common, additions of nitrogen from Russian-olive may contribute to stream nitrogen saturation, leading to eutrophication and oxygen deficiencies within the system (Mineau et al. 2011). Along Deep Creek in southeast Idaho, Mineau et al. (2012) determined that allochthonous organic matter inputs from Russian-olive leaf litter and the recalcitrant nature of Russian-olive leaves caused a decrease in ecosystem efficiency. In that study, inputs of allochthonous organic matter increased 25-fold after Russian-olive

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invasion and was most likely stored as benthic organic matter in the stream (Mineau et al. 2012).

Russian-olive also appears to be providing a subsidy to the invasive, exotic common carp, *Cyprinus carpio* L. For example, in Deep Creek, ID, Russian-olive materials (principally the fruits themselves) make up approximately two-thirds of the stomach content of common carp (K. Heinrich and C. Baxter, Idaho State University, personal communication). Carp have been found to be responsible for a multitude of deleterious ecosystem and community-level effects, such as decreases in vegetation cover and waterfowl use (Bajer et al. 2009), alterations of water quality (Parkos et al. 2003), and decreases in native fish abundance (Weber and Brown 2011), thus making its invasion in North American freshwater systems a major concern. Furthermore, common carp has been found to decrease the growth (Wahl et al. 2011; Wolfe et al. 2009) and abundance (Weber and Brown 2011) of native fish species. It is therefore possible that Russian-olive may be facilitating carp's dominance in some rivers.

In the United States, Russian-olive, along with saltcedar (*Tamarix* spp., Tamaricaceae), has the potential to serve as nesting habitat for the endangered southwestern willow flycatcher (USDA 2012). Additionally, the threatened yellow-billed cuckoo (*Coccyzus americanus* L., Cuculidae) has been observed to nest only in Russian-olive along a 230-km portion of the Rio Grande in New Mexico (Smith and Finch 2013). The use of Russian-olive by sensitive native avian species has led to conflicts between groups advocating for endangered species preservation on one hand and those promoting invasive species management on the other (Hultine et al. 2010). Nonnative plant species have been found to host a lower diversity and abundance of insects, which could potentially affect bird fledgling rates (Tallamy 2004); however, very little is known about this process for Russian-olive. Russian-olive is commonly used by foliage nesters (Stoleson and Finch 2001), but use by cavity nesters is rare (Bateman and Paxton 2010; but see Smith and Finch 2013).

Anecdotally, birders in the Okanagan Valley in southern BC have reported a variety of overwintering, berry-feeding birds consuming the fruits of Russian-olive, including Western Bluebirds, American Robins, Northern Flicker, Bohemian and Cedar Waxwings, Varied Thrush, and European Starlings. In the same region, there are areas where Russian-olive has completely replaced all native woody vertical vegetative structures, thereby acting as the sole vertical structure for tree-nesting avian species. Clearly, a formal assessment of native bird use of Russian-olive within western Canada is warranted.

Information regarding insect use of Russian-olive in western Canada is also lacking, but several interesting observations have been made. L.K.D.C observed extensive feeding and habitation on Russian-olive fruits by yellowjacket wasps (*Vespula* sp.) near Kamloops and Vernon, BC, in October 2013 (Figure 6). Similar observations involving yellowjacket use of Russian-olive have been informally reported on the Internet (http://community.stretcher.com/forums/p/18888/197111.aspx, http://www.countrylivinginacariboovalley.com/uncategorized/how-to-kill-wasps/). It would be interesting to determine whether Russian-olive is subsidizing food resources for the yellowjacket. Insect surveys conducted in Okanagan observed insects from the orders Thysanoptera, Hymenoptera, Hemiptera, Coleoptera, Diptera, Dermaptera, Psocoptera, Ephemeroptera, Trichoptera, and Orthoptera to be associated with Russian-olive (Collette and Pither, unpublished data).

Potential for Management and Control

Multiple control methods are in the process of being developed for Russian-olive in the United States. Mechanical control methods, such as mowing, cutting, and bulldozing, have been used, but with varying success (Katz and Shafroth 2003). Additionally, these techniques can often have undesirable consequences; removal of Russian-olive can cause severe soil disturbances, leading to increased erosion (Stannard et al. 2002), and the invasive species is often replaced by other exotic species (Gaddis and Sher 2012).

Biological control is a method currently being explored. However, because Russian-olive is valued as an ornamental in North America, testing of candidate arthropod biocontrol agents in Europe by the Centre for Agricultural Bioscience International (CABI) and Biotechnology and Biological Control Agency has focused on agents that only attack Russian-olive flower buds, flowers, fruits, seeds, and seedlings. These types of agents would reduce the reproductive output of the tree and its spread while simultaneously preserving the horticultural value of existing trees (Bean et al. 2008). Promising host-specific agents include *Aceria angustifoliae* Denizhan (Acari: Eriophyoidae), a mite which galls inflorescences, young fruits, leaves, and shoots, and *Ananarsia eleagnella* Kuznetzov (Lepidoptera: Gelechiidae), a fruit- and seed-feeding moth (CABI 2013, 2014). Currently, the program is in the foreign exploration phase, which involves surveying for and host range testing of potential agents within Russian-olive's native range (Bean et al. 2008; CABI 2011, 2014). The next planned phase for the United States will focus on rearing and testing potential agents at the proposed U.S. Department of Agriculture quarantine facilities in Temple, TX, and Sidney, MT (Bean et al. 2008). Testing the mentioned candidate biocontrols for use in Canada has been postponed until information regarding Russian-olive's invasiveness in Canada becomes available (R. De Clerck-Floate, personal communication).

Although Russian-olive has yet to be classified as noxious or even "of concern" by any Canadian provinces, invasive

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Figure 6. (Upper) Yellowjacket (*Vespula* sp.) on Russian-olive. (Lower left) Yellowjacket chewing on a Russian-olive fruit. (Lower right) holes in Russian-olive fruits caused by yellowjacket feeding. (Color for this figure is available in the online version of this paper.)

species managers are taking notice. As in the United States, suppression programs for Russian-olive in western Canada face challenges from potential conflicts between different stakeholders (see above). They are also subject to the same logistical challenges experienced in the United States, including removal along stream banks leading to destabilization and erosion (Pollen-Bankhead et al. 2009). The following example illustrates these challenges. Russian-olive suppression was initiated along a portion of the Milk River north of the Alberta/Montana border in 1999 and involved cutting trees and saplings (COSEWIC 2012; Pearce and Smith 2009). The stumps were then treated with the herbicide triclopyr in 2000 and 2001 (COSEWIC 2012; Pearce and Smith 2009). However, a follow-up study

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conducted in 2005 observed that the herbicide-treated stumps had begun to resprout vigorously, and 236 new plants had established in the area (Pearce and Smith 2009).

To the best of our knowledge, there are currently no substantial or coordinated control programs for Russian-olive in Canada, and efforts that we have witnessed (e.g., in the Okanagan Valley of BC) have been haphazard at best. Russian-olive is still available for consumer purchase as an ornamental in Canada, further compromising management efforts. At greenhouses and nurseries, information about Russian-olive is often incomplete or misleading. For example, during a recent visit to a Calgary, Alberta, greenhouse, L.K.D.C. found Russian-olive for sale, the tag indicating it was "native to many areas", with no mention of it being nonnative to Canada. Also, recommendations discouraging planting Russian-olive in close proximity to bodies of water are not readily disseminated to consumers.

Anticipated Effects and Future Research Needs

Potential Invasion Range in North America. Acquiring accurate information about the current distribution of Russian-olive in Canada is a priority. Furthermore, regions in Canada that support the conditions favorable for Russian-olive growth (see above) should be the focus of research and management. Russian-olive is believed to be limited in its southern distribution, perhaps because of a lack of chilling needed for bud break and germination (Friedman et al. 2005; Guilbault et al. 2012); however, nothing is known about its northern distribution limits. Gusta et al. (1983) determined that Russian-olive branches were killed at −55°C, suggesting that a maximal northern limit does exist. Based on current occurrence records, it appears Russian-olive's distribution has not reached this limit. Previous studies have shown that if climate warming trends continue, Russian-olive's southward invasion within the United States could be limited (Friedman et al. 2005; Guilbault et al. 2012). However, no studies have focused on the projected climate change effects on northward expansion (i.e., in Canada). Its ability to tolerate cold climates (Friedman et al. 2005; Gusta et al. 1983) suggests Russian-olive's invasion front could easily shift northward from affected states in the United States.

The possibility of using "citizen science" as a means to record Russian-olive locations is promising. Volunteers have been used to survey Russian-olive in the United States (Brown et al. 2001; Crall et al. 2011) and have also been used to survey other weedy shrubs and trees, including *Lonicera* species (Caprifoliaceae) (Brandon et al. 2003), *Rosa multiflora* Thunb. (Rosaceae) (Brandon et al. 2003), *Celastrus orbiculatus* Thunb. (Celastraceae) (Ibáñez et al. 2009), and *Rhamnus cathartica* L. (Rhamnaceae) (Brandon et al. 2003; Brown et al. 2001). This citizen science approach is promising for three reasons. First, because of

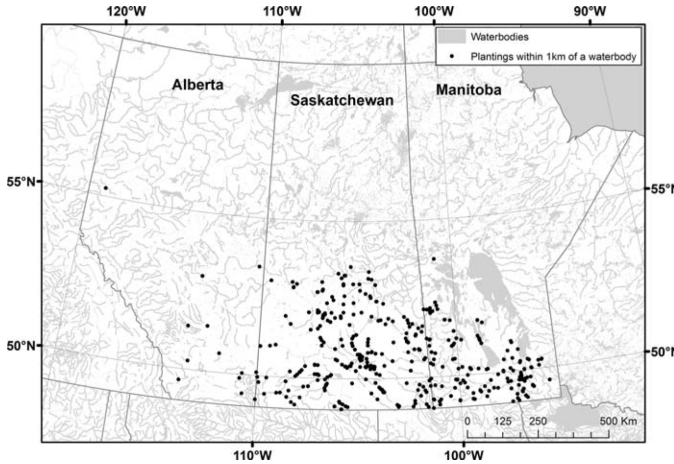

Figure 7. Russian-olive plantings that have the potential to naturalize in areas within 1 km of a waterbody. Projection as in Figure 2.

Russian-olive's popularity as an ornamental, the majority of Russian-olive plantings occur in urban areas and are located on private land. Generally, property owners are reasonably knowledgeable of the plants located on their property. Second, Russian-olive is easily identified (Crall et al. 2011) through its long, silvery-grey leaves and sharp thorns, which decreases the probability of misidentification. Third, tools and software used to record invasive plant locations, such as web-based application and mobile phone applications, are readily available to the public and easy to use. In addition to assisting Russian-olive research, citizen science can help increase awareness about Russian-olive's potential for invasion and allows taxpayers to participate in and understand Russian-olive research and management, to which they indirectly contribute financially.

The potential extent of Russian-olive's invasion in Canada is currently unknown and needs to be assessed formally. Planting records and outcomes from across the Canadian prairies can potentially be used as baseline data to determine potential areas of invasion. Waterbodies and riparian areas in close proximity to Russian-olive plantings may facilitate establishment of this plant and should be closely monitored as high risk for invasion. Although more detailed research is required, preliminary observations by the authors indicate Russian-olive in western Canada typically spreads aggressively within ca. 1 km of waterbodies, which is consistent with observations in the United States (Lesica and Miles 1999; Madurapperuma et al. 2013; Narumalani et al. 2009; Pearce and Smith 2001).

Using the Census of Canada Digital Boundary Files Rivers and Lakes shapefiles (Statistics Canada 2006), we identified 535 plantings (comprising 93,875 Russian-olive plants) that occurred within 1 km of waterbodies and thus have the potential to naturalize and invade (Figure 7). This comprises 16% of the total plantings with known locations

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and 22% of the total number of individual Russian-olives seedlings that were planted (known locations). As these figures do not include the plantings with unknown locations (382 of 3,777 plantings, or 10% of plantings), more plantings may in fact fall within this area of high naturalization risk. However, discussions with landowners have revealed that Russian-olive plantings are often unsuccessful, requiring replanting in many prairie areas (G. Michener, U. Lethbridge, personal communication). Especially valuable would be surveys aimed at determining the fates of Russian-olive plants from different planting periods (e.g., Figure 3) and within different climatic and soil regions. Data from such surveys could inform efforts to predict the current and future distribution of Russian-olive (see below).

Ecological niche modeling (ENM) is a powerful tool currently being used to predict potential plant invasions (Fiaboe et al. 2012; Peterson and Vieglais 2001; Peterson et al. 2003; Sobek-Swant et al. 2012; Thuiller et al. 2005). A recent scientometric analysis, which analyzes trends, patterns, and irregularities in publications of a particular field, determined that there has been a growing interest in using ecological niche models to predict invasive species distribution over the past decade (Barbosa et al. 2012). ENM could also be very useful for determining Russian-olive's potential spread in Canada, as it has been with many other invasive species in Canada and the United States (Anderson et al. 2006; Bradley 2009; Ensing et al. 2013; Mau-Crimmins et al. 2006). When coupled with the prairie planting data, the niche model predictions could be used to identify areas of concern for Russian-olive invasion and, in turn, can be used to guide management plans.

Ecosystem Effects. The combined effects of differences in plant life history between Russian-olive and co-occurring native species and altered hydrology have caused changes to successional pathways among riparian areas the United States (Friedman et al. 1997; Strange et al. 1999). As previously mentioned, in contrast to native cottonwoods, Russian-olive germination and seedling establishment is not flood dependent, and seedlings can establish under the canopy layer (Reynolds and Cooper 2010; Shafroth et al. 1995). Increased flood regulation through damming has led to fewer flooding events, decreased peak flow, and in turn, a decrease in the physical force of water to move sediment downstream. This decreased peak flow has reduced stream meandering, a process necessary to create point bars (where sediment accumulates on the inner bank of a meandering stream) and establish cottonwood germination sites (Friedman et al. 1997). With fewer point bars, cottonwood establishment and regeneration is limited, thereby shifting the successional processes to favor species that do not require flooding events to establish, such as Russian-olive (Friedman et al. 1997; Strange et al. 1999). The beginning of this successional shift has been observed along eastern (Lesica and Miles 2001) and northern (Pearce and Smith 2001) Montana rivers. Although these findings concern rivers in the United States, Canadian rivers are subject to similar flow regulation regimes and structures (Bradley and Smith 1986; Dynesius and Nilsso 1994; Rood et al. 2005) and might therefore experience similar fates. For instance, abrupt flow reductions and insufficient summer flows have been observed to be partly responsible for riparian cottonwood declines downstream of the St. Mary Dam in southern Alberta (Rood et al. 1995). Furthermore, historic declines in annual flow have been observed along the same portion of the Old Man River in southern Alberta (Rood et al. 2005), where Russian-olive invasion from backyard plantings has been observed (R. De Clerck-Floate, personal communication).

Russian-olive's potential to subsidize streams in the United States with nitrogen and allochthonous organic matter raises concern for Canadian aquatic ecosystems. The shift from a semiarid/riparian grassland to one dominated by woody plants, as appears to be happening with Russian-olive in some areas of southern Alberta, is expected to affect nutrient dynamics and hydrologic function (Ball et al. 2010; Huxman et al. 2005). It follows that any magnitude of inputs of nutrient matter, organic matter, or both from these new woody inhabitants, especially from nitrogen fixing exotics such as Russian-olive, will also have profound effects on the system.

Community and Species Effects. Currently, peer-reviewed research concerning the potential effects of Russian-olive on Canada's native flora and fauna is lacking. A recently published report from the Committee on the Status of Endangered Wildlife in Canada (COSEWIC) raised concerns about the invasion of Russian-olive and its potential displacement of native plants important to Weidemeyer's Admiral (*Limenitis weidemeyerii* W. H. Edwards, Lepidoptera: Nymphalidae), a brush-footed butterfly of special concern (COSEWIC 2012).

Russian-olive invasion along river systems in southern Alberta, especially along the Milk River basin, may also affect the survival and reproduction of Mountain Sucker (*Catostomus platyrhynchus* Cope, Catostomidae) (Boguski and Watkinson 2013). The Mountain Sucker is primarily a benthic feeder, browsing on algae, diatoms, and small invertebrates (Belica and Nibbelink 2006). If Canadian streams face the same fate as Deep Creek, ID, increases in benthic organic matter will have unknown effects on habitat quality for this fish. From an economic and ecological standpoint, any negative effects of Russian-olive on fishery-related waterways, such as the salmon-bearing rivers in British Columbia, could be devastating. As such, Russian-olive invasion effects on Mountain Sucker and on the aquatic community in general require further study.

Russian-olive's subsidization of other invasive species is also a concern. As mentioned previously, the common carp's dominance over native species may be facilitated by Russian-olive. Carp's potential distribution (Zambrano et al. 2006) overlaps the potential distribution of Russian-olive predicted by Peterson et al. (2003). It is possible, therefore, that carp could already be present in areas where Russian-olive has invaded or is predicted to invade. Areas in southern BC appear to bear this out; Russian-olive has extensively invaded areas near Kamloops, Penticton, and Osoyoos (L. Collette, personal observation), the same areas where common carp have been reported (Froese and Pauly 2014).

Conclusion

Recent research in the United States on invasive riparian plants and their ecological impacts, such as saltcedar and Russian-olive, provides a strong foundation for comparable research in Canada. Based on our literature review, we have identified five key research questions to guide research on Russian-olive in Canada.

1. What is Russian-olive's current and potential distribution in North America? Existing niche model predictions (Hoffman et al. 2008; Jarnevich and Reynolds 2011; Peterson et al. 2003) were not informed by Canadian occurrence records, nor did they consider potentially important abiotic predictors of Russian-olive distribution. Future niche models should address these limitations.
2. What capacity does Russian-olive have to escape cultivation and naturalize in and invade Canadian ecosystems? Studies such as those by Pearce and Smith (2001, 2009) are informative, but future research could benefit from the application of molecular (e.g., Le Roux and Wieczorek 2009; Novak and Mack 2001), dendrochronology, or both methods (e.g., Holmes et al. 2014; Kasson et al. 2013) for estimating rates of spread from putative source plants.
3. What ecosystem-level impacts will Russian-olive invasion have? For example, will Russian-olive alter nutrient cycling and shift succession patterns in Canadian rivers, as it has in the United States?
4. What are the community-level effects of Russian-olive? How might plant, bird, insect (e.g., pollinators), and fish communities be affected? For example, will the insect community associated with Russian-olive be depauperate, as has been found with other nonnative plants (e.g., Tallamy 2004)?
5. What species-level impacts will Russian-olive have, with initial focus on rare and endangered species? For example, the habitat of Weidemeyer's Admiral, a butterfly of special concern in Canada, and the Mountain sucker, a threatened species in Alberta, may be lost or altered by Russian-olive invasion.

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Literature Cited

Anderson RP, Peterson AT, Egbert SL (2006) Vegetation-index models predict areas vulnerable to purple loosestrife (*Lythrum salicaria*) invasion in Kansas. Southwest Nat 51:471–480

Arnold RH, Straby AE (1973) *Phomopsis elaeagni* on Russian olive (*Elaeagnus angustifolia*) in Canada. Can Plant Dis Surv 53:183–186

Bajer PG, Sullivan G, Sorensen PW (2009) Effects of a rapidly increasing population of common carp on vegetative cover and waterfowl in a recently restored Midwestern shallow lake. Hydrobiologia 632:235–245

Ball BA, Kominoski JS, Adams HE, Jones SE, Kane ES, Loecke TD, Mahaney WM, Martina JP, Prather CM, Robinson TMP, Solomon CT (2010) Direct and terrestrial vegetation-mediated effects of environmental change on aquatic ecosystem processes. BioScience 60: 590–601

Barbosa FG, Schneck F, Melo AS (2012) Use of ecological niche models to predict the distribution of invasive species: a scientometric analysis. Braz J Biol 72:821–829

Bartish IV, Jeppsson N, Nybom H, Swenson U (2002) Phylogeny of *Hippophae* (Elaeagnaceae) inferred from parsimony analysis of chloroplast DNA and morphology. Syst Biol 27:41–54

Bateman HL, Paxton EH (2010) Saltcedar and Russian olive interactions with wildlife. Pages 51–59 *in* Shafroth PB, Brown CA, Merritt DM, eds. Saltcedar and Russian Olive Control Demonstration Act Science Assessment. Reston, VA: U.S. Geological Survey Scientific Investigations Report 2009–5247, 143 p

Bean D, Norton A, Jashenko R, Cristofaro M, Schaffner U (2008) Status of Russian olive biological control in North America. Ecol Restor 26:105–107

Belica LT, Nibbelink NP (2006) Mountain Sucker (*Catostomus platyrhynchus*): A Technical Conservation Assessment. USDA Forest Service, Rocky Mountain Region. Laramie, WY: University of Wyoming. 62 p

Boguski DA, Watkinson DA (2013) Information in Support of a Recovery Potential Assessment of Mountain Sucker (*Catostomus platyrhynchus*), Milk River Populations (Designatable Unit 2). Ottawa, ON: Fisheries and Oceans Canada Canadian Science Advisory Secretariat Research Document 2013/028. 42 p

Borell AE (1962) Russian-Olive for Wildlife and Other Conservation Uses. Washington, DC: U.S. Department of Agriculture Leaflet 517. 8 p

https://doi.org/10.1614/IPSM-D-14-00037.1 Published online by Cambridge University Press

Bradley BA (2009) Regional analysis of the impacts of climate change on cheatgrass invasion shows potential risk and opportunity. Glob Change Biol 15:196–208

Bradley CE, Smith DG (1986) Plains cottonwood recruitment and survival on a prairie meandering river floodplain, Milk River, southern Alberta and northern Montana. Can J Bot 64:1433–1442

Brandon A, Spyreas G, Molano-Flores B, Carroll C, Ellis J (2003) Can volunteers provide reliable data for forest vegetation surveys? Nat Areas J 23:254–261

Brock JH (1998) Invasion, ecology and management of *Elaeagnus angustifolia* (Russian olive) in the southwestern U.S.A. Pages 372 *in* Starfinger U, Edwards K, Kowarik I, Williamson M, eds. Plant Invasions: Ecological Mechanisms and Human Response. Leiden, The Netherlands: Backhuys Publishers

Brown CR (1990) Avian Use of Native and Exotic Riparian Habitats on the Snake River, Idaho. M.A. thesis. Fort Collins, CO: Colorado State University. 60 p

Brown WT, Krasny ME, Schoch N (2001) Volunteer monitoring of nonindigenous invasive plant species in the Adirondack Park, New York, USA. Nat Areas J 21:189–196

[CABI] Centre for Agricultural Bioscience International (2009) Biological Control of Russian Olive, *Elaeagnus angustifolia*: Annual Report 2008. Delémont, Switzerland: CABI. 30 p

CABI (2011) Biological control of Russian olive, *Elaeagnus angustifolia*: Annual Report 2010. Delémont, Switzerland: CABI. 22 p

CABI (2013) Biological Control of Russian Olive, *Elaeagnus angustifolia*: Annual Report 2012. Delémont, Switzerland: CABI. 23 p

CABI (2014) Biological Control of Russian Olive, *Elaeagnus angustifolia*: Annual Report 2013. Delémont, Switzerland: CABI. 23 p

Catling PM, Oldham MJ, Sutherland DA, Brownell VR, Larson BMH (1997) The recent spread of autumn-olive, *Elaeagnus umbellata*, into southern Ontario and its current status. Can Field Nat 111:376–380

[COSEWIC] Committee on the Status of Endangered Wildlife in Canada (2012) COSEWIC Assessment and Status Report on the Weidemeyer's Admiral *Limenitis weidemeyerii* in Canada. Ottawa, ON: COSEWIC. http://publications.gc.ca/collections/collection_2013/ec/CW69-14-282-2012-eng.pdf. Accessed February 26, 2014

Crall AW, Newman GJ, Stohlgren TJ, Holfelder KA, Graham J, Waller DM (2011) Assessing citizen science data quality: an invasive species case study. Conserv Lett 4:433–442

DeCant JP (2008) Russian olive, *Elaeagnus angustifolia*, alters patterns in soil nitrogen pools along the Rio Grande River, New Mexico, USA. Wetlands 28:896–904

Douglas GW, Meidinger DV, Pojar J (1999) Illustrated Flora of British Columbia, Volume 3: Dicotyledons (Diapensiaceae through Onagraceae). Victoria, BC: British Columbia Ministry of Environment, Lands, and Parks and Ministry of Forests. 423 p

Dynesius M, Nilsso C (1994) Fragmentation and flow regulation of river systems in the northern third of the world. Science 266:753–762

Ensing DJ, Moffat CE, Pither J (2013) Taxonomic identification errors generate misleading ecological niche model predictions of an invasive hawkweed. Can J Bot 91:137–147

[ESRI] Environmental Systems Research Institute (2012) ArcGIS Desktop. Redlands, CA: Environmental Systems Research Institute

Esser LL (1995) Fire Effects Information System. *Shepherdia argentea*. http://www.fs.fed.us/database/feis/. Accessed September 4, 2013

Evergreen Native Plant Database (2013) Native Plant Database. http://nativeplants.evergreen.ca/. Accessed April 15, 2013

Fiaboe KKM, Peterson AT, Kairo MTK, Roda AL (2012) Predicting the potential worldwide distribution of the red palm weevil *Rhynchophorus ferrugineus* (Olivier) (Coleoptera: Curculionidae) using ecological niche modeling. Fla Entomol 95:659–673

Follstad Shah JJ, Harner MJ, Tibbets TM (2010) *Elaeagnus angustifolia* elevates soil inorganic nitrogen pools in riparian ecosystems. Ecosystems 13:46–61

Friedman JM, Auble GT, Shafroth PB, Scott ML, Merigliano MF, Freehling MD, Griffin ER (2005) Dominance of non-native riparian trees in western USA. Biol Invasions 7:747–751

Friedman JM, Scott ML, Auble GT (1997) Water management and cottonwood forest dynamics along prairie streams. Pages 48–71 *in* Knopf FL, Samson FB, eds. Ecology of Great Plains Vertebrates and Their Habitats. New York: Springer-Verlag

Froese R, Pauly D, eds. (2014) FishBase. Version (11/2014). http://www.fishbase.org. Accessed March 2014

Gaddis M, Sher A (2012) Russian olive (*Elaeagnus angustifolia*) removal in the western United States: multi-site findings and considerations for future research. Sustainability 4:3346–3361

Guilbault KR, Brown CS, Friedman JM, Shafroth PB (2012) The influence of chilling requirement on the southern distribution limit of exotic Russian olive (*Elaeagnus angustifolia*) in western North America. Biol Invasions 14:1711–1724

Gusta LV, Tyler NJ, Chen TH (1983) Deep undercooling in woody taxa growing north of the $-40°C$ isotherm. Plant Physiol 72: 122–128

Hansen NE (1901) Ornamentals for South Dakota. Brookings, SD: U.S. Experiment Station, South Dakota Bull. 72. 206 p

Hilu KW, Borsch T, Müller K, Soltis DE, Soltis PS, Savolainen V, Chase MW, Powell MP, Alice LA, Evans R, Sauquet H, Neinhuis C, Slotta TAB, Rohwer JG, Campbell CS, Chatrou LW (2003) Angiosperm phylogeny based on *matK* sequence information. Am J Bot 90:1758–1776

Hoffman JD, Narumalani S, Mishra DR, Merani P, Wilson RG (2008) Predicting potential occurrence and spread of invasive plant species along the North Platte River, Nebraska. Invasive Plant Sci Manage 1: 359–367

Holmes KA, Greco SE, Berry AM (2014) Pattern and process of fig (*Ficus carica*) invasion in a California riparian forest. Invasive Plant Sci Manage 7:46–58

Hultine KR, Belnap J, van Riper C III, Ehleringer JR, Dennison PE, Lee ME, Nagler PL, Snyder KA, Uselman SM, West JB (2010) Tamarisk biocontrol in the western United States: ecological and societal implications. Front Ecol Environ 8:467–474

Huss-Danell K (1997) Actinorhizal symbioses and their N_2 fixation. New Phytol 136:375–405

Huxman TE, Wilcox BP, Breshears DD, Scott RL, Snyder KA, Small EE, Hultine K, Pockman WT, Jackson RB (2005) Ecohydrological implications of woody plant encroachment. Ecology 86:308–319

Ibáñez I, Silander JA Jr, Wilson AM, LaFleur N, Tanaka N, Tsuyama I (2009) Multivariate forecasts of potential distributions of invasive plant species. Ecol Appl 19:359–375

James RL (1983) Cankers of Russian-Olive Seedlings at the Montana State Forest Tree Nursery. Missoula, Montana: U.S. Department of Agriculture Forest Service Northern Region Report 83-8. 6 p

Jarnevich CS, Reynolds LV (2011) Challenges of predicting the potential distribution of a slow-spreading invader: a habitat suitability map for an invasive riparian tree. Biol Invasions 13:153–163

Kasson MT, Davis MD, David DD (2013) The invasive *Ailanthus altissima* in Pennsylvania: a case study elucidating species introduction, migration, invasion, and growth patterns in the northeastern US. Northeast Nat 20:1–60

Katz GL, Friedman JM, Beatty SW (2001) Effects of physical disturbance and granivory on establishment of native and alien riparian trees in Colorado, U.S.A. Divers Distrib 7:1–14

Katz GL, Shafroth PB (2003) Biology, ecology and management of *Elaeagnus angustifolia* L. (Russian olive) in western North America. Wetlands 23:763–777

Kindschy RR (1998) European starlings disseminate viable Russian-olive seeds. Northwest Nat 79:119–120

Knopf FL, Olson TE (1984) Naturalization of Russian-olive: implications to Rocky Mountain wildlife. Wildlife Soc B 12:289–298

https://doi.org/10.1614/IPSM-D-14-00037.1 Published online by Cambridge University Press

Kominoski JS, Follstad Shah JJ, Canhoto C, Fischer DG, Giling DP, González E, Griffiths NA, Larrañaga A, LeRoy CL, Mineau MM, McElarney YR, Shirley SM, Swan CM, Tiegs SD (2013) Forecasting functional implications of global changes in riparian plant communities. Front Ecol Environ 11:423–432

Le Roux J, Wieczorek AM (2009) Molecular systematics and population genetics of biological invasions: towards a better understanding of invasive species management. Ann Appl Biol 154:1–17

Lesica P, Miles S (1999) Russian olive invasion into cottonwood forests along a regulated river in north-central Montana. Can J Bot 77:1077–1083

Lesica P, Miles S (2001) Natural history and invasion of Russian olive along eastern Montana rivers. West N Am Nat 61:1–10

Li TSC, Schroeder WR (1996) Sea buckthorn (*Hippophae rhamnoides* L.): a multipurpose plant. HortTechnology 6:370–380

Little EL (1961) Sixty Trees from Foreign Lands. Washington, DC: U. S. Department of Agriculture, Agriculture Handbook 212. 29 p

Madurapperuma BD, Oduor PG, Anar MJ, Kotchman LA (2013) Understanding factors that correlate or contribute to exotic Russian-olive (*Elaeagnus angustifolia*) invasion at a wildland–urban interface ecosystem. Invasive Plant Sci Manage 6:130–139

Marchildon GP (2009) The Prairie Farm Rehabilitation Administration: climate crisis and federal–provincial relations during the Great Depression. Can Hist Rev 90:275–301

Mau-Crimmins TM, Schussman HR, Geiger EL (2006) Can the invaded range of a species be predicted sufficiently using only native-range data?: Lehmann lovegrass (*Eragrostis lehmanniana*) in the southwestern United States. Ecol Model 193:736–746

Miller IM, Baker DD (1985) The initiation, development and structure of root nodules in *Elaeagnus angustfolia* L. (Elaeagnaceae). Protoplasma 128:107–119

Mineau MM, Baxter CV, Marcarelli AM (2011) A non-native riparian tree (*Elaeagnus angustifolia*) changes nutrient dynamics in streams. Ecosystems 14:353–365

Mineau MM, Baxter CV, Marcarelli AM, Minshall GW (2012) An invasive riparian tree reduces stream ecosystem efficiency via a recalcitrant organic matter subsidy. Ecology 93:1501–1508

Moore AW (1964) Note on non-leguminous nitrogen-fixing plants in Alberta. Can J Bot 42:952–955

Muma W (2013) Ontario Trees & Shrubs, Autumn Olive. http://ontariotrees.com/main/species.php?id=2013. Accessed September 4, 2013

Nagler PL, Glenn EP, Jarnevich CS, Shafroth PB (2011) Distribution and abundance of saltcedar and Russian olive in the western United States. Crit Rev Plant Sci 30:508–523

Narumalani S, Mishra DR, Wilson R, Reece P, Kohler A (2009) Detecting and mapping four invasive species along the floodplain of North Platte River, Nebraska. Weed Technol 23:99–107

Novak SJ, Mack RN (2001) Tracing plant introduction and spread: genetic evidence from *Bromus tectorum* (cheatgrass). BioScience 51: 114–122

Oliver A (2001) Special Crops Factsheet: Sea Buckthorn. Kamloops, BC: British Columbia Ministry of Agriculture, Food and Fisheries. 4 p

Olson TE, Knopf FL (1986) Naturalization of Russian-olive in the western United States. West J Appl For 1:65–69

Parkos JJ III, Santucci VJ Jr, Wahl DH (2003) Effects of adult common carp (*Cyprinus carpio*) on multiple trophic levels in shallow mesocosms. Can J Fish Aquat Sci 60:182–192

Pearce CM, Smith DG (2001) Plains cottonwood's last stand: can it survive invasion of Russian olive onto the Milk River, Montana floodplain? Environ Manage 28:623–637

Pearce CM, Smith DG (2009) Rivers as conduits for long-distance dispersal of introduced weeds: example of Russian olive (*Elaeagnus angustifolia*) in the northern Great Plains of North America. Pages 410–427 *in* VanDevender TR, Espinosa-Garcia FJ, Harper-Lore BL, Hubbard T, eds. Invasive Plants on the Move: Controlling Them in North America. Tucson, AZ: The University of Arizona Press and The Arizona-Sonora Desert Museum

Pendleton RL, Pendleton BK, Finch D (2011) Displacement of native riparian shrubs by woody exotics: effects on arthropod and pollinator community composition. Nat Resour Environ Issues 16:Article 25

Peterson AT, Papes M, Kluza DA (2003) Predicting the potential invasive distributions of four alien plant species in North America. Weed Sci 51:863–868

Peterson AT, Vieglais DA (2001) Predicting species invasions using ecological niche modeling: new approaches from bioinformatics attack a pressing problem. BioScience 51:363–371

Pollen-Bankhead N, Simon A, Jaeger K, Wohl E (2009) Destabilization of streambanks by removal of invasive species in Canyon de Chelly National Monument, Arizona. Geomorphology 103:363–374

Reynolds LV, Cooper DJ (2010) Environmental tolerance of an invasive riparian tree and its potential for continued spread in the southwestern US. J Veg Sci 21:733–743

Richardson DM, Pyšek P, Rejmánek M, Barbour MG, Panetta FD, West CJ (2000) Naturalization and invasion of alien plants: concepts and definitions. Divers Distrib 6:93–107

Riffle JW (1977) First report of vesicular-arbuscular mycorrhizae on *Elaeagnus angustifolia*. Mycologia 69:1200–1203

Rood SB, Mahoney JM, Reid DE, Zilm L (1995) Instream flows and the decline of riparian cottonwoods along the St. Mary River, Alberta. Can J Bot 73:1250–1260

Rood SB, Samuelson GM, Weber JK, Wywrot KA (2005) Twentieth-century decline in streamflows from the hydrographic apex of North America. J Hydrol 306:215–233

Savolainen V, Chase MW, Hoot SB, Morton CM, Soltis DE, Bayer C, Fay MF, De Bruijn AY, Sullivan S, Qiu YL (2000) Phylogenetics of flowering plants based on combined analysis of plastid *atpB* and *rbcL* gene sequences. Syst Biol 49:306–362

Shafroth PB, Auble GT, Scott ML (1995) Germination and establishment of the native plains cottonwood (*Populus deltoides* Marshall subsp. *monilifera*) and the exotic Russian-olive (*Elaeagnus angustilfolia* L.). Conserv Biol 9:1169–1175

Shafroth PB, Brown CA, Merritt DM, eds. (2010) Saltcedar and Russian olive control demonstration act science assessment. Reston, VA: U.S. Geological Survey Scientific Investigations Rep. 2009-5247

Smith DM, Finch DM (2013) Use of native and nonnative nest plants by riparian-nesting birds along two streams in New Mexico. River Res Applic. DOI:10.1002/rra.2713

Sobek-Swant S, Kluza DA, Cuddington K, Lyons DB (2012) Potential distribution of emerald ash borer: what can we learn from ecological niche models using Maxent and GARP? Forest Ecol Manage 281:23–31

Soltis DE, Soltis PS, Chase MW, Mort ME, Albach DC, Zanis M, Savolainen V, Hahn WH, Hoot SB, Fay MF, Axtell M, Swensen SM, Prince LM, Kress WJ, Nixon KC, Farris JS (2000) Angiosperm phylogeny inferred from 18S rDNA, *rbcL*, and *atpB* sequences. Bot J Linn Soc 133:381–461

Stannard M, Ogle D, Holzworth L, Scianna J, Sunleaf E (2002) History, Biology, Ecology, Suppression and Revegetation of Russian-Olive Sites (*Elaeagnus angustifolia* L.). Boise, ID: U.S. Department of Agriculture National Resources Conservation Service Plant Materials Technical Note MT-43

Statistics Canada (2006) Census of Canada Digital Boundary Files. http://hdl.handle.net/10573/41743. Accessed June 20, 2013

Stevens PF (2013) Angiosperm Phylogeny Website, Version 12, July 2012. http://www.mobot.org/MOBOT/research/APweb/welcome.html. Accessed April 17, 2013

Stoleson SH, Finch DM (2001) Breeding bird use of and nesting success in exotic Russian olive in New Mexico. Wilson Bull 113:452–455

Strange EM, Fausch KD, Covich AP (1999) Sustaining ecosystem services in human-dominated watersheds: biohydrology and ecosystem processes in the South Platte River Basin. Environ Manage 24:39–54

Sytsma KJ, Morawetz J, Pires JC, Nepokroeff M, Conti E, Zjhra M, Hall JC, Chase MW (2002) Urticalean rosids: circumscription, rosid ancestry, and phylogenetics based on *rbcL*, *trnLF*, and *ndhF* sequences. Am J Bot 89:1531–1546

Tallamy DW (2004) Do alien plants reduce insect biomass? Conserv Biol 18:1689–1692

Thuiller W, Richardson DM, Pyšek P, Midgley GF, Hughes GO, Rouget M (2005) Niche-based modelling as a tool for predicting the risk of alien plant invasions at a global scale. Glob Change Biol 11: 2234–2250

[USDA] U.S. Department of Agriculture (2012) Field Guide for Managing Russian Olive in the Southwest. Albuquerque, NM: USDA Forest Service Southwestern Region TP-R3-16-24. 11 p

Wahl DH, Wolfe MD, Santucci VJ Jr, Freedman JA (2011) Invasive carp and prey community composition disrupt trophic cascades in eutrophic ponds. Hydrobiologia 678:49–63

Weber MJ, Brown ML (2011) Relationships among invasive common carp, native fishes and physicochemical characteristics in upper Midwest (USA) lakes. Ecol Freshw Fish 20:270–278

Wolfe MD, Santucci VJ Jr, Einfalt LM, Wahl DH (2009) Effects of common carp on reproduction, growth, and survival of largemouth bass and bluegills. Trans Am Fish Soc 138:975–983

Young JA, Young CG (1992) Seeds of Woody Plants in North America. Portland, OR: Dioscorides Press. 407 p

Zambrano L, Martínez-Meyer E, Menezes N, Peterson AT (2006) Invasive potential of common carp (*Cyprinus carpio*) and Nile tilapia (*Oreochromis niloticus*) in American freshwater systems. Can J Fish Aquat Sci 63:1903–1910

Zhang S, Soltis DE, Yang Y, Li D, Yi T (2011) Multi-gene analysis provides a well-supported phylogeny of Rosales. Mol Phylogenet Evol 60:21–28

Zheng H, Wu Y, Ding J, Binion D, Fu W, Reardon R (2006) Invasive Plants of Asian Origin Established in the United States and Their Natural Enemies. Volume 1. Morgantown, WV: U.S. Department of Agriculture Forest Service. 147 p

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