State of Michigan's Species Profile for Purple Jewelweed (*Impatiens glandulifera*) Management

Created December, 2023

Introduction/Scope

*Impatiens glandulifera (*purple jewelweed) is an annual plant species native to the Himalayan region of India and Pakistan. The species was originally introduced as an ornamental garden plant to the United Kingdom in 1839 and was first reported in North America in Canada in 1901 (Clements et al., 2008). The species is now found throughout much of Europe and is spreading through the Americas. The spread of *Impatiens glandulifera* has become such a concern that in Europe the European Commission's DASIE (Delivering Alien Invasive Species Inventory for Europe) now rates it as one of the 100 worst species in Europe (Ammer et al., 2011). The species was first reported in Michigan in 1912 in Port Huron and has been detected in three Michigan counties: Alger, Chippewa, and St. Clair (Michigan Flora, 2023). In addition to displacing native flora, the species present a risk to the health of riparian areas as their shallow root systems leave the riverbanks they invade more susceptible to erosion. There are also concerns that purple jewelweed could alter the behavior of pollination insects to the detriment of native flowering plants (MISIN, 2023*).* Purple jewelweed is a Watch List species in Michigan (Invasive Species: Watch List, 2023).

Synonyms

Common Name: Himalayan balsam, Indian balsam, policeman's helmet, ornamental jewelweed, jewelweed.

This document is a product of an Environmental Protection Agency Great Lakes Restoration Initiative subgrant between the Michigan Department of Natural Resources and Lake Superior State University. It was made for the purposes of:

- Consolidating the current science-based knowledge on the biology and ecology of purple jewelweed.
- Summarizing the scientific literature and research that informs the management of purple jewelweed in Michigan.
- Identifying future directions for research relative to successful purple jewelweed management in Michigan

This document was written by Sam Mitchell under the direction of Dr. Megan Butler and was reviewed by the Michigan Departments of Natural Resources and Agriculture and Rural Development. This document references peer-reviewed journals and publications. Any chemical, company, or organization that is mentioned was included for its involvement in peer-reviewed, published, publicly shared information, not to imply endorsement of the chemical, company, or organization.

Biology and Ecology

I. Identification

Purple jewelweed (*Impatiens glandulifera)* is an annual invasive plant that ranges from 0.6 to 3 m in height. The leaves of the plant of the plant are lanceolate to elliptical in shape, are shiny with pinkish veins, and range in length from 6 to 15 cm. The leaves are either opposite or come in whorls of three and are sharply serrated, with 18 to 50 teeth (Clements et al., 2008*)*.

The stems of the plant are generally 5 to 50 mm wide. Stems are erect to ascending with some being branched. The stems themselves are bright green but may have a purplish tinge to them and are glabrous. Throughout most of the length, the stems are hollow and have a central watery pith. The branches of the stems have glandular stipules in the nodes that resemble fingers (Clements et al., 2008). The roots of purple jewelweed are 15 to 20 cm long with a lignified exterior and a central watery pith. Roots are relatively short and shallow compared to native species. The roots of the plant are adventitious, arising from the stem of the plant rather than just root tissue, allowing purple jewelweed to produce roots from the stem if the plant is blown over (Clements et al., 2008).

Figure 1. Flowers and fruit of purple jewelweed (Samanek 2023a)

The distinctive flowers of purple jewelweed (Figure 1) are one of the main reasons for the plant being imported. Fragrant summer flowers have a unique shape that has been compared to a traditional policeman's helmet; they have hollow, domed-tube shaped corolla with a wide front opening. These flowers have five petals and range from pinkish to purplish red, blue, or white in color and often have purplish spots (Clements et al., 2008). Blooms have three sepals, are irregular, and are found on elongated stalks (MISIN, 2023). The fruit of purple jewelweed are capsules around 1.5 to 2.5 cm in length which contain six to eight

Figure 2. Seeds of purple jewelweed (Samanek 2023b)

seeds. Seeds start green in color but as they mature, turn brown and then eventually black. The seeds are generally spherical in shape and typically four to seven millimeters in diameter (Figure 2). The fruit of the plant is elastically dehiscent, meaning that the seed pods will burst if touched when ripe, allowing seeds to spread out as far as five to seven meters away from the parent plant, depending on the height of the seed pods above the ground and the strength and direction of the wind (Clements et al., 2008; Varia et al., 2016; Beerling & Perrins, 1993). This allows purple jewelweed seeds to spread farther than plants that rely on gravity for seed dispersal.

Figure 3. 1839 botanical drawing of Impatiens bicolor (left) and Impatiens glandulifera (purple jewelweed; right) (Royle. 1839)

A few species that could be mistaken for purple jewelweed are orange jewelweed (*Impatiens capensis*), pale touch-me-not *(Impatiens pallida)*, and bicolor balsam *(Impatiens bicolor)* (Figure 3). The flowers of purple jewelweed can be used to help differentiate it from other similar-looking species (Clements et al., 2008). Orange jewelweed has smaller flowers that can be yellow or orange. The leaves of this plant are rounded and have fewer serrations on them. The pale-touch-me-not also has rounded leaves, yellow flowers, and fewer serrations than purple jewelweed (Clements et al., 2008; MISIN, 2023). The height of the plant can be used to distinguish it from other similar species because, at 0.6 to 3 meters in height, purple jewelweed is generally taller than similar species (Clements et al., 2008).

II. Detection

Purple jewelweed is most likely to establish in places like emergent marshes, Great Lakes marshes, wet meadows, wet prairies, shrub swamps, floodplain forests, and deciduous forests (Higman et al., 2010), and often invades riparian areas such as riverbanks and the surrounding areas (Tanner, 2017). Surveys for purple jewelweed should prioritize these likely to be invaded environments (Higman et al., 2010). It is imperative to identify purple jewelweed invasion early due to the plant's ability to quickly establish and become a monoculture stand (Figure 4). The best method of detecting the invasion of purple jewelweed early is to conduct manual visual inspections of likely invasion sites. Identification of purple jewelweed in the field is relatively easy at plant maturity because it is one of the tallest

Figure 4. Purple jewelweed taking over a riverbank. (Samanek 2023c)

annual plant species and has distinctive “policeman’s helmet” shaped purple/pink flowers (Clements et al., 2008; invasive Species: Watch List, 2023). Purple jewelweed typically begins to emerge in April. Therefore the best time to detect purple jewelweed is during the early summer when the plant has grown at least 10 cm tall allowing it to be differentiated from background foliage, but before it has produced seed pods (IRD Duhallow LIFE Project, 2015).

In Michigan, community members can help identify the sites of possible purple jewelweed invasions by reporting them to their local CISMAs or using apps such as the Midwest Invasive Species Information Network (MISIN) app to report sightings (Applied Spatial Ecology and Technical Services, 2023). Remote sensing methods such as the use of high-resolution aerial or satellite imagery are also being developed for invasive species such as purple jewelweed (Cheng et al., 2007). Unmanned Aerial Systems (UAS) technology is also rapidly developing and presents a cost-effective way to detect invasions. Another method of gathering images is to attach a camera to a car or train to take pictures of the landscape; algorithms can be used to identify the plant (Karim, 2021). More research is needed to understand the utility of these methods as well as other remote detection methods like eDNA in improving the detection of purple jewelweed.

III. Life History and Spread/Dispersal

Reproduction

The purple jewelweed is an annual plant that primarily reproduces through seeds, which mature in the summer and begin sprouting the following year in the early summer. The flowers and seeds of purple jewelweed are notably prolific with their season extending longer than many native plants, giving them an advantage over many native plants in an area (Wood et al., 2021). Purple jewelweed has been found to flower at different times based on local growing conditions. For example, plants growing in open fields with ample sunlight flower in June while plants in more shaded areas flower from July onward; plants in heavily shaded areas can flower as late as August and September (IRD Duhallow LIFE Project, 2015). There does not appear to be any difference in the reproductive strategies of the plant in its native areas and invasive range.

Purple jewelweed flowers are mainly pollinated by insects, but the species can self-pollinate as well. The species is well suited for pollination by bumble bees due to an abundance of nectar and the layout of their flowers; the petals surround the bee, resulting in the backs of the bee coming into contact with the stamens and stigmas of the flower effectively covering the bee in pollen. This results in a higher rate of fertilization of the next flower they enter (Chittka & Schurkens, 2001; Ghazoul, 2002; Thijs et al., 2012).

Purple jewelweed is part of the ornamental garden trade and is currently not regulated in Michigan (Invasive Species: Prohibited and Restricted, 2023). The plant is sometimes shared among individuals and clubs (Grzesiak, 2023). Its large, showy flowers may be prized by gardeners for their looks as well as apparent popularity with pollinators. Selling and sharing of

seeds and young plants can lead to populations of this plant turning up in new locations far from apparent sources (Niemiera & Von Holle, 2009).

Purple jewelweed can produce up to 2,500 seeds per plant (Varia et al., 2016), however the number of seeds produced can vary based on growing conditions. Plants growing in colder more northern latitudes do not grow as large and produce fewer seeds; the amount of precipitation that an area receives and an area's soil moisture could be good indicators of how well the plant will grow in an area also, with plants growing best in moist, warm regions (Clements et al., 2008; Varia et al., 2016). Purple jewelweed seeds require exposure to cold temperatures to break dormancy. Seeds can also float and germinate underwater, and typically remain viable for around 18 months (Beerling & Perrins, 1993; Kelly et al., 2008), but if they are fully hydrated and stored at 20°C they can remain dormant for several years (Mumford, 1988; Cao, L., L. Berent, and A. Fusaro, 2023).

Due to the species' ability to thrive in riparian areas, float and germinate underwater, purple jewelweed is well-suited to spreading its seeds by water. Seeds can travel underwater near the channel bottom and be deposited up to ten kilometers downstream (IRD Duhallow LIFE Report, 2015). Flooding events can also spread seeds a greater distance, With some studies showing sites subjected to flooding can have twice as many purple jewelweeds compared to areas without floods (Čuda et al., 2017). In addition, floods disturb native vegetation and displace nutrients, making it easier for purple jewelweed to establish in disturbed areas (Čuda et al., 2017).

IV. Habitat

Native Range

Purple jewelweed is native to the mountainous Himalayan region of India and Pakistan. In its native habitat, the species is generally found at altitudes between 2,000 and 2,500 m with some instances of the plant growing up to 4,000 m. The native habitat of purple jewelweed tends to be cool and wet with a relatively high amount of precipitation (Clements et al., 2008). The plant grows in wetter areas such as ditches, roadsides, pastures, and woodlands, as well as on the edges of forests. It is often found in the pastures and scrublands of Himalayan cedar and the mixed forest zone (Čuda et al., 2020). In its native range, purple jewelweed does not form large monocultures due to the presence of native competitors and diseases. For example, a species that helps to keep purple jewelweed in check in its native range is the rust fungus *Puccinia komarovii* var. *glandulifera* (Ellison et al., 2020).

Invasive Range

Purple jewelweed has spread far out of its native range with anthropogenic help. Europeans helped to spread the plant out of its native region to be used as an ornamental or as a curiosity in botanical gardens. Letters exist showing that the two notable naturalists Charles Darwin and his friend Joseph Dalton hooker traded seeds (Darwin Correspondence Project, 2023). Thanks to this help the plant is now in found Europe, North America, South America, and New Zealand (Figure 5). The northernmost limit of the invasive range of the species is around 64° N in places

such as Canada, Alaska, and Norway. It is still grown and sold ornamentally; some gardeners prize it for its showy blooms and rapid growth, as well as its ability to attract hummingbirds.

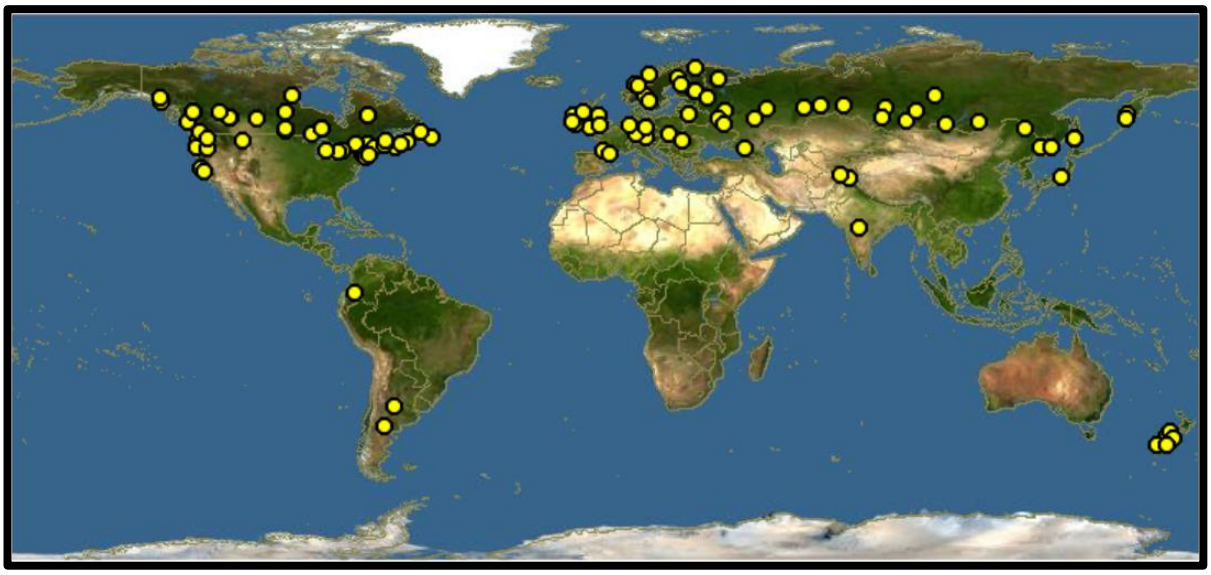

Figure 5. Distribution of purple jewelweed around the world (Polistes Corporation, 2023)

While in its native range purple jewelweed is found at altitudes from 2,000 to 4,000 meters, in its invasive range it can be found at much lower altitudes, often in riparian areas. Purple jewelweed also thrives in wet and cool environments in its invasive range. Areas that have a high amount of precipitation are more likely to be amenable to the invasion of the species. However, there are some cases of the plant invading places that have lower annual precipitation but sufficient soil moisture to support its growth (Clements et al., 2008). Invasions of purple jewelweed tend to start along rivers and spread from there, including into forests (Čuda et al., 2020).

Purple jewelweed can establish in new areas and become invasive due to the plant's ability to tolerate a wide range of environmental conditions. Soil conditions can range from fine to coarse alluvium as well as mineral soils and peats. Purple jewelweed has been found to tolerate pH as low as 3.4 or as high as 7.6 (Clements et al., 2008). The plant is also tolerant of low nutrient levels. Finally, a wide variety of moisture levels (ranging from 15 to 53%) are tolerated by the plant. Rapid growth coupled with its ability to reach great heights and form dense monocultures allows purple jewelweed to shade out native plants and dominate the habitats that it invades in a short time (Clements et al., 2008; Tanner et al., 2020; Wood et al., 2021). Another reason purple jewelweed is a successful invader is the species' high phenotypic plasticity. This ability to vary traits based on the environment gives the plants an advantage when establishing themselves in new environments. This helps facilitate its spread by allowing it to expand into both unshaded disturbed environments as well as overcrowded shaded environments (Gruntman et al., 2019; Wood et al., 2021). Effects of the Invasive Species

Negative Ecological Effects

Purple jewelweed can have a wide range of negative impacts on native ecosystems. First, purple jewelweed can reduce native plant diversity, fungal diversity, and invertebrate diversity due to its ability to take over large swaths of an area and turn it into a monoculture no longer conducive to native diversity (Oliver et al., 2020; Kiełtyk and Delimat 2019; Gaggini et al. 2019; Pattison et al. 2016; Seeney et al. 2019). A field study conducted in the United Kingdom (UK) demonstrated that in areas where purple jewelweed had become established and begun to out-compete native flora, there was also a reduction in the diversity of above-ground invertebrates such as detritivores, herbivores, and predators (Tanner et al., 2013).

Purple jewelweed can alter the microbial community of the soil by reducing the growth of native mycorrhizal fungi, which form symbiotic relationships with native species, facilitating their growth. The shifts that purple jewelweed facilitates are beneficial to its survival and reproduction but detrimental to native plants (Tanner et al., 2013; Pattison et al., 2016). Purple jewelweed is also associated with an increase in erosion in invaded areas, as its shallow root systems are unable to hold down soil as well as native vegetation. When plants die off in the winter, they leave the sites they occupied bare and unprotected from erosion (Clements et al., 2008; Greenwood et al., 2020). This erosion leads to sedimentation of rivers which can negatively affect sensitive species of fish and invertebrates (IRD Duhallow LIFE Project, 2015).

Purple jewelweed also produces nectar that entices pollinators to visit the species much to the detriment of native species (Ghazoul, 2002). The nectar sugar concentration of purple jewelweed is similar to that of other plants that bumble bees frequent at around 48%. However, purple jewelweed outcompetes native flowers in the rate at which it produces its sugar. Sugar production in purple jewelweed flowers is around 0.47 ± 0.12 milligrams per flower per hour, exceeding the nectar production of most native flowering plants. This rapid production of sugar entices pollinators to return to purple jewelweed rather than native competitors (Chittka & Schurkens, 2001; Clements et al., 2008; Ghazoul, 2002). Experiments simulating an invasion of purple jewelweed have found that pollinators are more likely to visit the highly rewarding flowers of purple jewelweed than native plants that produce sugar at a slower rate (Chittka & Schurkens, 2001).

Economic Effects

Due to its ability to impact native ecosystem biodiversity and promote soil erosion and sedimentation, purple jewelweed is important to manage. Established purple jewelweed is projected to cost the European Union states €1–1.5 million per year to control (Tanner et al. 2017). The cost of eliminating the species on the national scale in the European Union has been estimated to be in the hundreds of millions in total. In 2003 the UK environmental agency estimated that eliminating the plant in the UK could cost £174–350 million (Environment Agency, 2003; Tanner et al. 2017). Switzerland estimates that it could cost €1.2–6.4 million to eliminate 95% of purple jewelweed in the Canton of Zurich (Tanner et al. 2017). In 2008 control costs in the UK averaged around £0.50/m^2 for a single herbicide treatment. Costs go up to £10/m^2 if the work is done manually and habitat restoration costs are included (Pollard, 2017).

A key take-away from Europe's experience with purple jewelweed is that prevention is the cheapest course of action when it comes to managing the species.

Positive Effects

Purple jewelweed can have some positive effects. Purple jewelweed may be an effective bio-accumulator (a plant that can uptake pollutants for disposal) of cadmium (Coakley et al, 2021) as the seeds of purple jewelweed can survive exposure to high levels of cadmium (Cd); its seeds still germinate in as much as 1000 mg/kg Cd (Coakley et al., 2021). It could also be beneficial to the pollinator species it attracts because purple jewelweed produces an abundance of nectar for pollinator species to feed on (Chittka & Schurkens, 2001). The high sugar production gives native pollinators and honeybees an abundant source of food. Because purple jewelweed flowers persist into the late summer, they have been used by beekeepers as a late source of nectar for their hives (Čuda et al., 2020). Finally, purple jewelweed along with other invasive species can be repurposed into various products. The flowers of purple jewelweed can be used to make a natural purple dye. Purple jewelweed dye will wash off with water, but is suitable for printing on papers not directly exposed to harsh sunlight (Maja Klančnik, 2021).

Current Status and Distribution in Michigan

Purple jewelweed is found throughout the northern region of the United States (Figure 6). Currently, the species is mainly distributed in the Northern Upper Peninsula in Michigan, but it is also starting to be found on the east side of the Lower Peninsula (Figure 7). Recently the plant has also been found on Mackinac Island (Hindy, 2023).

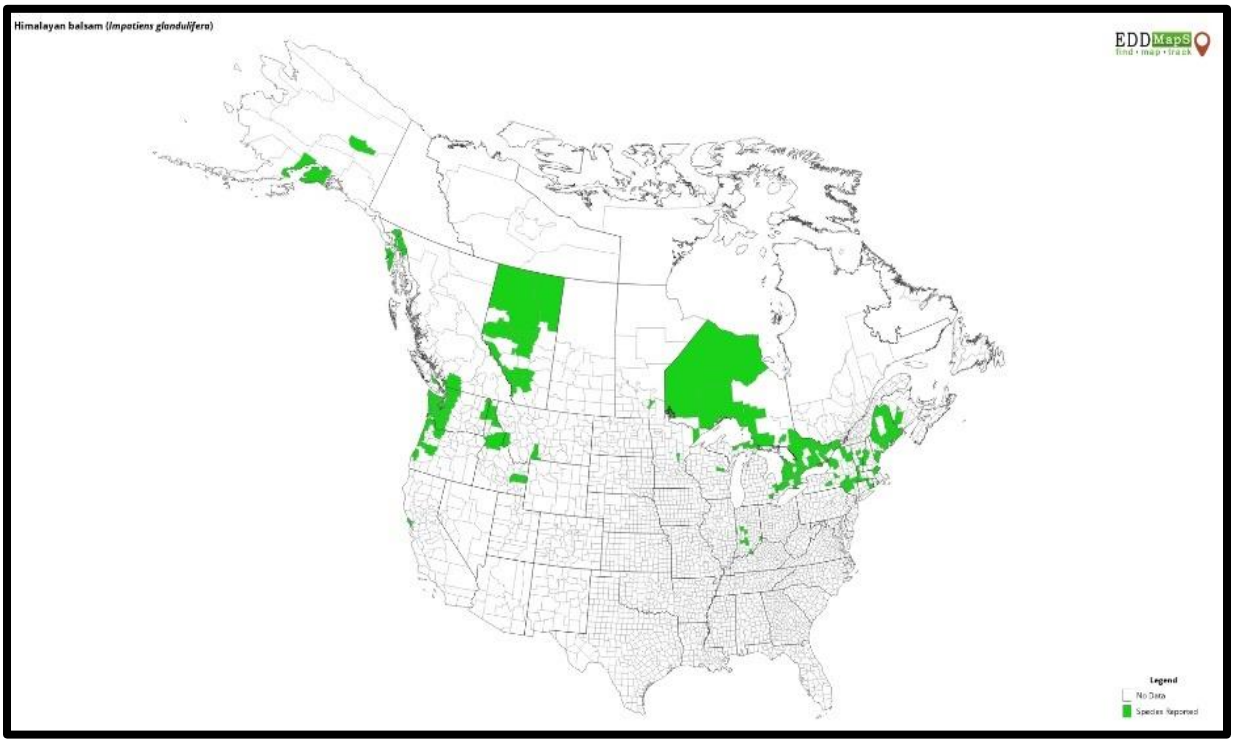

Figure 6. Range of purple jewelweed in North America. (EDDMapS 2023a)

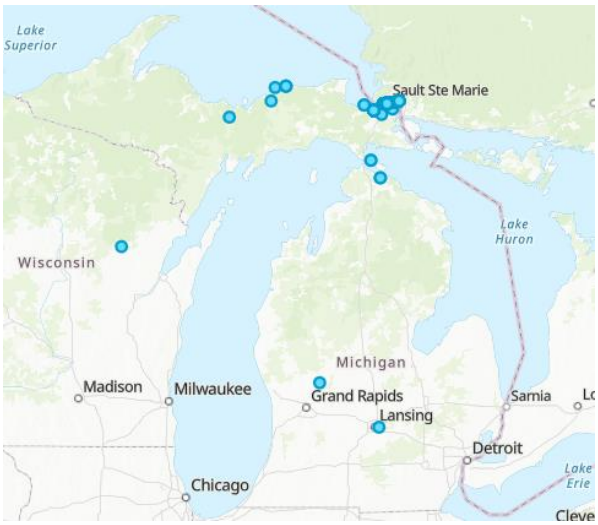

Figure 7. Purple jewelweed known distribution in Michigan (Midwest Invasive Species Information Network 2023)

Management

I. Prevention

Purple jewelweed has long been a problem in many European countries, where it was first introduced around 1839 (Clements et al., 2008; Čuda et al., 2017). Because of the long history Europe has had with purple jewelweed, there is a wealth of resources produced by the European Union scientists and policymakers regarding management (Helmisaari, 2010; Tanner, 2017). The first basic measure that can be implemented to prevent the spread of purple jewelweed is a ban on keeping, importing, selling, breeding, and growing of the plant. Purple jewelweed seeds are the target of such measures because the sale of live plants is not common (Tanner, 2017). To contain the spread of purple jewelweed it is also necessary to inform the public why the sale of the plant has been banned. Detailed information should be given explaining the negative impacts that the species have on native ecosystems. Partnerships can be formed with environmental non-government organizations to disseminate information about the species and the measures being taken against them to the public (Kelly et al., 2008).

Phytosanitary measures such as inspections, quarantines, and treatments can be implemented to help prevent the unintentional spread of purple jewelweed to new areas (Tanner, 2017). Because purple jewelweed seeds can linger in soils for up to 18 months, it is important to ensure that soil contaminated with seeds is not spread (Kelly et al., 2008). Preventative control efforts should especially focus on areas connected by flowing water due to purple jewelweed's ability to spread many kilometers downriver from its original location (Clements et al., 2008).

II. Management/Control

Key Considerations

Controlling a purple jewelweed invasion, like other invasive plants, is labor-intensive and requires a substantial amount of time and resources (Oliver et al., 2020). Managing established populations of purple jewelweed requires significant resources deployed over several years (Oliver et al., 2020). To control the spread of purple jewelweed, it is critical to detect invasions early while the population is small and before the plants reproduce and spread. Early preventative measures ultimately save time and resources (Oliver et al., 2020).

The explosive nature of purple jewelweed seed pods poses a unique challenge. If management must take place when the seed pods are ripe, care must be taken to ensure that they do not explode and spread their seeds during management efforts. It should also be noted that where the stands are found nearby bodies of water, management will have to take place throughout the catchment. The process of eliminating purple jewelweed should start upstream and work downstream due to the plant's ability to spread far downstream. Special care must also be taken when removing the plant from river banks as removing them could leave the banks without any root systems to provide structure, keep sediment in place and prevent erosion (Tanner, 2017; Kelly et al., 2008). Due to an increased risk of erosion, efforts should be undertaken to replant native plants quickly to prevent erosion and reduce the risk of other invasive plants taking over the treated area.

Physical or Manual Control

Thanks to the rather shallow root system and annual life cycle, purple jewelweed can be hand-pulled relatively easily. Cutting is also a viable option; when cutting the plant, the cut must be below the first node to prevent possible regrowth (Oliver et al., 2020). After the cutting or pulling is done in an area, the plant material must be removed from the site and disposed of due to purple jewelweed's ability to regrow from the shoots; even small plants can develop flowers and seeds (Oliver et al., 2020; Helmisaari, 2010). When purple jewelweed is found in riparian areas, increasing erosion becomes a concern. Hand-pulling the plants in these areas can disrupt the soil structure as well as leaves pockets of open soil, increasing the risk of erosion during the winter months. Techniques such as cutting and trimming with a weed-wacker should be preferred over pulling to minimize soil disruption and erosion in these areas (Clements et al., 2008; Drury, 2020; Helmisaari, 2010).

In Europe, the optimum time to conduct cutting and pulling is when the plant is in the early regenerative stage, occurring at the end of July (Helmisaari, 2010). Cutting the plant before this stage allows the plant to regrow, while cutting after this stage risks seed formation (Oliver et al., 2020). In Michigan the timeline for control is similar, pulling starts in late June and ends in early August (Hindy, 2023).

If the seed pods of the plant have ripened before the plant could be removed, measures must be undertaken to ensure that the pods do not rupture and spread their seeds. One method of

prevention is to cover the seed pods with a plastic bag and then cut them from the stem of the plant. This method was highly successful at preventing the spread of the seeds with at least 70% of the seeds being contained using this method (IRD Duhallow LIFE Project, 2015).

There are also some thermal methods of controlling purple jewelweed. The effects that thermal options have on the plants are dependent on the temperature that the plant is exposed to and the amount of time that the plant is exposed to that temperature. Plants in different stages of development respond differently to heat with seeds and smaller younger plants being easier to treat with this method (Oliver et al., 2020). The first thermal method is flaming, where a small torch is used to burn the plants before flowering. However, some of the plants treated with this method can recover (Clements et al., 2008).

Another treatment method that has been experimented with is hot water treatment. In this method, hot water is applied to the plants as well as the surrounding area to kill seeds. In lab trials, temperatures of at least 50 degrees Celsius (C) and above were needed for the water to be lethal to the seeds. Field trials of the method used 80 C water and showed that the cover of purple jewelweed was significantly lower after the hot water treatment (Oliver et al., 2020). After the hot water treatments bare soil space increased, raising concerns over erosion. The bare spaces created by this technique may necessitate revegetation efforts if native vegetation does not reestablish (Oliver et al., 2020). A potential increase in erosion may lead to an increase in sedimentation and negatively impact aquatic animals such as fish larvae and aquatic insects (IRD Duhallow LIFE Project, 2015). More research is needed to evaluate how this treatment affects the native seed banks of the treated area.

Chemical Control

The Purple jewelweed can be managed with the use of herbicides. Chemical control must be conducted according to the national and local regulations of the areas where the species invades (Tanner, 2017). Herbicides such as glyphosate and 2,4-D amine can be used to control large stands of purple jewelweed (Clements et al., 2008; Drury, 2020). Glyphosate and 2,4-D amine are applied twice per season early before the plant starts to flower, as plants sprayed after they have flowered can still produce viable seeds (Clements et al., 2008). In densely packed monoculture unselective glyphosate-based herbicides can be used without too much fear of harming native plants, however in less densely packed areas more selective types such as 2,4-D may be preferable to minimize collateral damage to native grasses (Kelly et al., 2008).

Special consideration must be given to the use of herbicides due to the plant's tendency to be found in riparian areas. It is important to take extra precautions while applying herbicide near water and use only aquatic-approved herbicides and surfactants (Tanner, 2017). However, using herbicides along the water source is not advised in many cases as erosion could increase to unacceptable levels; once purple jewelweed is killed off there may be nothing left to hold the sediment in place (Kelly et al., 2008).

Biological Control

Methods of biological controlling purple jewelweed are currently being studied. Research on biological control began in 2006 in the United Kingdom (Ellison et al., 2020). This testing focused on the possible introduction of antagonistic insects and fungi. This study showed that the insects, while effective at damaging the targeted purple jewelweed, also caused collateral damage to the native species of *Impatiens*. Research focused on using the rust fungus *Puccinia komarovii var. glanduliferae* has been more promising. This fungus is native to the Himalayan region and plays a role in keeping purple jewelweeds population in check by infecting and killing off dense populations and preventing them from forming a monoculture in its native habitat. Cross inoculation studies conducted with *I. glandulifera* and *I. parviflora* have shown that there are different and distinct variants of the fungus that can only infect their specific host species, making the fungus more suitable for use as a biological control. Testing has shown that the fungus could survive over winter (Ellison et al., 2020).

Grazing animals such as cattle, sheep and/or goats can also be used to control purple jewelweed. These animals graze on the leaves, stems, and flowers of the plant (Clements et al., 2008; Helmisaari, 2010). However, when purple jewelweed is found in riparian areas grazing could disturb the structure of the soil, cause stream bank destabilization, and lead to an increase in erosion (Wohl and Carline, 1996).

Research Needs

I. Biology and Ecology

There are several research gaps related to purple jewelweed ecology and biology. For example, it is unclear whether purple jewelweed's reproductive strategies differ between its native range and its invasive range. In addition, little in-depth research has been done on how long-established populations impact native ecosystems and food webs. Specifically, more research is needed to understand how purple jewelweed impacts riparian areas in the Northern United States. The species is currently associated with increased erosion and sedimentation. In the future, more research should be conducted to look specifically at the effects that purple jewelweed has on the water quality of the areas that it invades (Greenwood et al., 2020; IRD Duhallow LIFE Project, 2015). Finally, more research on how climate change will impact purple jewelweed and other invasive species will be helpful for research managers as they adapt to ever-changing conditions. For example, the invasive range of the plant could change along with changes in the climate (Figure 8).

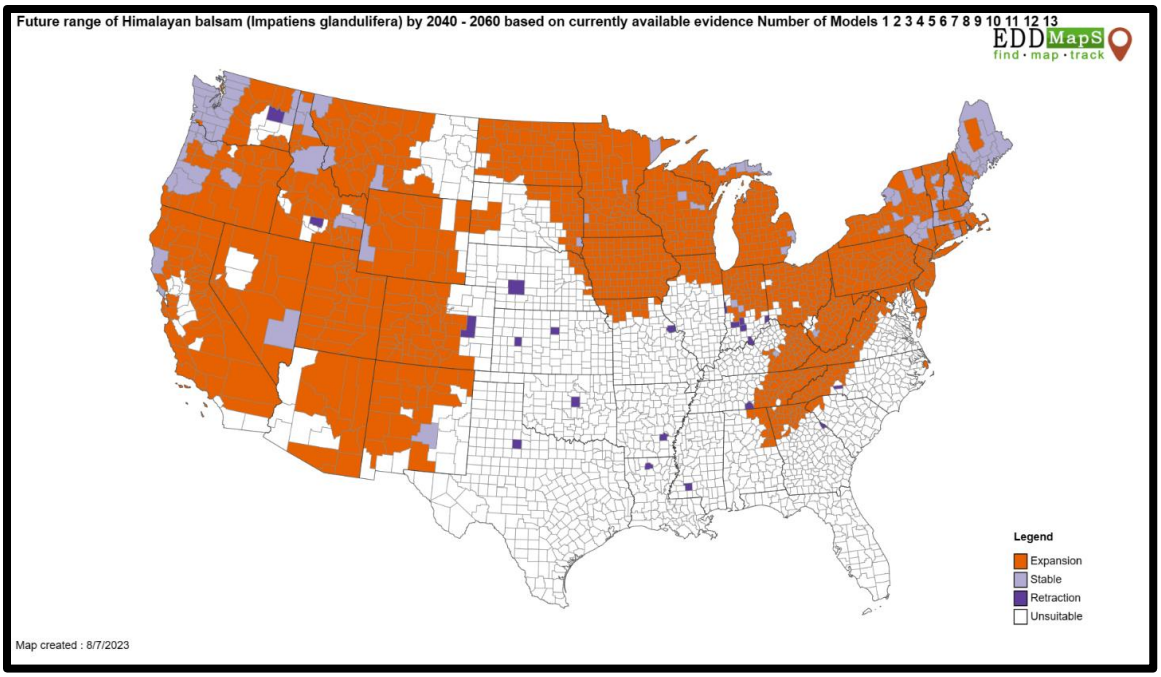

Figure 8. Potential future range of purple jewelweed (Impatiens glandulifera) based on 13 models. Map from the Early Detection & Distribution Mapping System (EDDMapS 2023b)

II. Detection

Continued research needs to be done on the use of remote detection techniques to identify invasive species like purple jewelweed. For example, the use of satellites and drones to produce high resolution imagery could be useful for purple jewelweed. More research is needed to understand the utility of these methods as well as other remote detection methods like eDNA in improving the detection of purple jewelweed. In addition, research focusing on modeling the potential distribution and expansion of existing purple jewelweed populations may be particularly helpful in improving early detection.

III. Management

There are several opportunities to inform and improve purple jewelweed management through research. First, more research needs to focus upon potential biological control opportunities. For example, more research needs to be conducted in North America on the effectiveness of the rust fungus *Puccinia komarovii var*. *glanduliferae* against the plant, ensuring that the fungus does not cause collateral damage among native species (Wood et al., 2021). In addition to this fungus, additional research may identify other potential biological control agents for the species. In addition, the use of water cutting during which plants are cut and then sprayed with hot water has shown potential as a management technique for purple jewelweed (Oliver et al., 2020). However, more research is needed to evaluate the non-target impacts of this treatment. For example, more research is necessary to understand the impacts of water cutting on native seed banks. In addition, more research is necessary to understand whether purple jewelweed

could be suitable for use in soil remediation efforts as a bio-accumulator. Finally, more research is needed to understand the short and long-term impacts of manual control methods such as hand-pulling on native ecosystems. Additional research on management impacts will help managers make informed decisions when choosing between different management techniques.

Future Directions for Michigan and Management

There are currently many opportunities for managing the spread of purple jewelweed in Michigan. Preventing the spread of the species is the first line of defense when it comes to protecting the state's valuable ecosystems. Consistent monitoring and management are necessary. In Michigan, there have been recommendations to create an early detection and response program. This sort of program could facilitate faster responses to outbreaks of invasive species in the state and allow workers to eradicate the problem before it spread out and become more difficult to control (Higman et al., 2010).

In addition, another measure that can be implemented to prevent the spread of purple jewelweed is a state policy banning the species from being imported, sold, bred, or grown (Tanner, 2017). Other countries including Canada have implemented such bans and can provide excellent examples of what works and does not work when implementing such policies. Along with any policy and management it is necessary to educate the public about the ecological impacts of the species and why it is being managed. Public education campaigns are valuable resources for managers trying to control the spread of species like purple jewelweed.

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