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Herbicides for management of waterhyacinth in the Sacramento–San Joaquin River Delta, California

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ABSTRACT

Waterhyacinth (*Eichhornia crassipes* (Mart.) Solms) is a global aquatic weed. Although a number of herbicides such as 2,4-D and glyphosate effectively control this plant, additional herbicides need to be evaluated to address concerns for herbicide stewardship and environmental restrictions on the use of herbicides in particular areas. Waterhyacinth has become a significant nuisance in the Sacramento–San Joaquin River Delta. The predominant herbicides for management of waterhyacinth in the Delta have been 2,4-D and glyphosate. However, environmental restrictions related to irrigation water residues and restrictions for preservation of endangered species are prompting consideration of the new reduced-risk herbicides imazamox and penoxsulam. Two trials were performed in floating quadrats in the Delta during the summer of 2016. In the first trial, two rates each of 2,4-D, glyphosate, imazamox, and penoxsulam were treated in four replicate quadrats. In this trial, the highest rates of all four herbicides provided greater than 80% control (2,4-D, 82%; glyphosate, 87%; imazamox, 93%; and penoxsulam, 94%). In the second trial, the lower rate of glyphosate (1,681 g a.e. ha^{-1}) was compared to four rates each of imazamox (187 to 1,494 g a.i. ha^{-1}) and penoxsulam (12 to 98 g a.i. ha^{-1}). In this trial, the highest rates of imazamox and penoxsulam provided 96 and 95% control, respectively, compared to the untreated reference. Imazamox and penoxsulam will provide suitable control of waterhyacinth as part of an operational program and may be used as part of an integrated pest management program with considerations of herbicide resistance management. In addition, incorporating these reduced-risk herbicides into the management program can reduce the amount of pesticides applied per acre to achieve waterhyacinth control.

Key words: *Eichhornia crassipes* (Mart.) Solms, Glyphosate, Imazamox, Penoxsulam, 2,4-D

INTRODUCTION

Waterhyacinth (*Eichhornia crassipes* (Mart.) Solms) is a free-floating, rosette-forming aquatic plant originally from South America (Pfingsten et al. 2017). It has been rated as the world's worst aquatic weed (Holm et al. 1977) and one of the world's worst 100 invasive alien species (Lowe et al. 2000). The Invasive Species Specialist Group reports that, as of the year 2000, it was reported in 50 countries on 5 continents (Lowe et al. 2000). Introduced to the United States at the Cotton Centennial Exposition in New Orleans in 1884, it spread rapidly throughout the southeastern United States soon thereafter and was documented to cause widespread navigation issues within 15 yr (Klorer 1909, Penfound and Earle 1948, Williams 1980). The U.S. Department of Agriculture Natural Resources Conservation Service (USDA-NRCS) (2017) currently reports it for 23 states and 1 Canadian province, and the U.S. Geological Service (USGS) reports observations of it in 38 states or territories (Pfingsten et al. 2017). Despite the severe worldwide economic impacts of this plant, waterhyacinth has been a staple of retail, mail order, and internet horticultural sales, with no legal restriction (Kay and Hoyle 2001, Reichard and White 2001, Maki and Galatowitsch 2004).

Waterhyacinth is a subtropical and tropical plant, sensitive to cold and freezing damage (Penfound and Earle 1948, Owens and Madsen 1995). Despite the sensitivity of foliage to frost damage, the stem bases may persist submerged in water (Owens and Madsen 1995). Therefore, the range of waterhyacinth may extend into more temperate regions than typically expected (Kriticos and Brunel 2016). Growth rates are controlled by plant density, nitrogen availability, and temperature (Center and Spencer 1981, Wilson et al. 2005). Plant reproduction and spread is largely vegetative, with the early stages of growth rapidly producing new rosettes (Barrett 1980a, Madsen 1993b). As density increases, new rosette formation stops, and carbon allocation shifts to leaf biomass (Madsen 1993b, Wilson et al. 2001). Barrett (1980a) studied flowering, fruit formation, and seed set in nine different populations of waterhyacinth from across the world. California populations were capable of both outcrossing and self-fertilization, with a high rate of seed set and viability. In surveying seed production in situ in 19 populations in tropical versus temperate locations, he found that seed production in temperate locations is much lower than tropical locations (Barrett 1980b). However, temperate zone populations still produce large numbers of

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viable seeds that could germinate under proper conditions. Despite this, Barrett (1980a) notes that vegetative propagation is more widespread than sexual propagation. This was validated by Zhang et al. (2010), who found that the genetic variability of introduced populations of waterhyacinth worldwide was low.

In subtropical Florida, growth of waterhyacinth is rapid, with biomass increasing as much as 1.5% per day, with a maximum biomass of 2.5 kg dry weight (DW) m^{-2} (Center and Spencer 1981). The midseason growth rates of subtropical sites (Florida and California) is comparable to growth rates for tropical regions of Africa, but more plants die back because of freezing conditions (Bock 1969). Spencer and Ksander (2005) also report growth rates for Sacramento–San Joaquin Delta (California) waterhyacinth similar to those in Florida. The rapid increase of these infestations has been shown to result in a number of economically and ecologically adverse impacts (Williams 1980, Council for Agricultural Science and Technology [CAST] 2000, CAST 2014). Waterhyacinth has been documented to displace native plants (Toft et al. 2003), reduce dissolved oxygen, and increase sedimentation (Rodriguez et al. 2012). For these reasons, management of this plant is often required to maintain the ecological and navigation services provided by the aquatic environment.

Management of waterhyacinth varies greatly across its range, depending on local political and economic factors. Although most governmental agencies name their approach as Integrated Plant Management, the details of these plans vary widely (Charudattan 1986). In South Africa, six biological control agents have been released: *Neochetina eichhorniae* Hustache, *Neochetina bruchi* Hustache, *Niphograpta albiguttalis* Warren (formerly *Sameodes albiguttalis*), *Orthogalumna terebrantis* Wallwork, *Eccritotarsus catarinensis* Carvalho, and *Cercospora piaropi* Tharp (Coetzee et al. 2011). Despite these releases, the desired level of control has not been achieved. In Florida, both *Neochetina* weevil species have been established, as well as the pyralid moth *N. albiguttalis*. In the Sacramento–San Joaquin River Delta (California), the only biological control agent to establish from releases in the 1980s is the weevil *N. bruchi* (Hopper et al. 2017). Though weevil densities are sufficiently high in some locations in California to suppress waterhyacinth growth, this effect is not observed in the Sacramento–San Joaquin River Delta.

Mechanical control options are widely used for management of waterhyacinth (Wolverton and McDonald 1979, Mathur and Singh 2004, Gettys 2014). In 2000, a legal decision halted herbicide treatments for waterhyacinth in the California Sacramento–San Joaquin River Delta, to allow for evaluation of nonchemical control options (Greenfield et al. 2006). Cutting or chopping did not maintain weed-free water surfaces. In areas in which water level can be controlled, summertime drawdown and desiccation has been used to control waterhyacinth (Gettys 2014). Although a wide array of other management techniques, such as the use of laser radiation (Couch and Gangstad 1974), have been investigated for plant management, the majority of these were not found to be operationally actionable.

Of approximately 300 active ingredients are registered as herbicides by the U.S. Environmental Protection Agency (USEPA), only 14 were labeled for aquatic use by 2014 (Netherland 2014). By 2017, the number of herbicides registered for aquatic use increased to 16 (Aquatic Ecosystem Restoration Foundation [AERF] 2017). Of these 16 active ingredients, only 10 have been recommended by the registrants for use on waterhyacinth. Five of these active ingredients (diquat, glyphosate, imazapyr, triclopyr, and 2,4-D) have been recommended independently of the registrant by university extension and outreach for control of waterhyacinth, and six have efficacy data published in a peer-reviewed venue (diquat, glyphosate, imazamox, penoxsulam, triclopyr, and 2,4-D).

The herbicide 2,4-D has a long history as a chemical treatment to control waterhyacinth that extends back to its development in 1948 (Gallagher 1969). In addition to maintenance management of waterhyacinth with 2,4-D, the Florida waterhyacinth control program encouraged the establishment of the weevil *N. eichhorniae* (Zeiger and McGehee 1977). Maintenance management in Florida is considered a success in that, of the 1,283 ha (3,172 acres) of floating weeds in public lakes, 92% occur in infestations of 4 ha or less; as recently as 1959, floating weeds covered 50,600 ha of Florida public waters (Phillips 2016). During 1 yr, the State of Florida floating plant control program spent $4.4M US to control 13,800 ha of mixed waterhyacinth and waterlettuce. During this time period, the State of Florida applied 5,810 kg a.e. (12,800 lb a.e.) of 2,4-D, predominantly for control of waterhyacinth (Phillips 2015).

The Sacramento–San Joaquin River Delta (hereafter referred to as "Delta") is formed by the confluence of the Sacramento River, flowing from the north, and the San Joaquin River, flowing from the south. The large tidal estuary comprises 3,370 km^2 (1,300 square miles) of diked islands, waterways, and marshland (Delta Stewardship Council [DSC] 2013). The Delta forms the nexus of the water transportation system in California, and water from the Delta is pumped into the California aqueduct to serve irrigation and domestic water use in southern California. Water is also taken directly from the Delta for irrigation of farmland within the Delta itself. Delta water serves 27 million people in California and irrigates 1.2 M ha (3 M acres) of farmland in the state. The Delta ecosystem supports more than 800 species of plants and animals, of which more than 250 are special-status species with legal or regulatory protection (DSC 2013). Under the federal Endangered Species Act, listed anadromous species (e.g., Pacific salmon) are regulated by the National Marine Fisheries Service (NMFS), and other endangered species are regulated by the U.S. Fish and Wildlife Service (USFWS). Species listed under the State of California Endangered Species Act are regulated by the California Department of Fish and Wildlife (CDFW). Aquatic plant management activities must include plans to avoid any impacts on more than 30 different species in agreements with these and other agencies (California Department of Parks and Recreation, Division of Boating and Waterways [CDBW] 2017). In addition to its importance for water transport and wildlife, the Delta is used by ocean-going vessels to access the ports of Sacramento and Stockton. The Delta is also used for recreational boating, fishing, hunting, birdwatching, and camping (DSC 2013).

Herbicide treatments were initiated by U.S. Bureau of Reclamation in 1978, and the Water Hyacinth Task Force formed in 1983. California Boating and Waterways has made herbicide applications since 1983. The herbicide 2,4-D was the predominant herbicide used to control waterhyacinth early in the history of the Delta's waterhyacinth control program (WHCP), which is operated by the CDBW. In 2010, the WHCP used 1,515 kg a.e. of formulated 2,4-D and 198 kg a.e. of formulated glyphosate (CDBW 2010). This has reversed in recent years, with glyphosate now comprising 78% of the waterhyacinth control program (CDBW 2017). Specifically, CDBW used 5,640 kg a.e. of glyphosate and 1,600 kg a.e. of 2,4-D in control operations during 2016 (CDBW 2017). This transition away from 2,4-D is the result of regulatory pressure to use reduced-risk herbicides and reduce the total input of pesticides into the Delta, combined with restrictions on when and where specific herbicides were used to protect endangered species. In addition, 2,4-D use near irrigation intakes is restricted by USEPA label restrictions; state and county agricultural use restricts use of 2,4-D close to certain crops because of concerns regarding volatility and drift. The USFWS and NOAA NMFS restrict use of 2,4-D in certain areas of the Delta and during certain times of the year because of concerns for endangered fish species such as the delta smelt (*Hypomesus transpacificus* McAllister), migrating Pacific salmon (*Oncorhynchus* spp.), and habitat conservation for the valley elderberry longhorn beetle (*Desmocerus californicus dimorphus* Fisher), among many other restrictions. Because this trend of greater restrictions is likely to continue, additional reduced-risk herbicides are needed for the CDBW program for foliar application on waterhyacinth. To be added to the list of available herbicides for the control program, toxicological testing is required not only on the specific endangered species in the list for the Delta, but also on species that provide habitat or in the food web of these species. The cost of adding additional herbicide (and surfactants) is very high. Many herbicides are simply considered too toxic by the regional regulatory authorities (e.g., USFWS, NMFS, and state agencies) to be used in the Delta for controlling aquatic vegetation.

Since 1994, the USEPA has managed the Conventional Reduced Risk Pesticide Program to achieve the goal of bringing less toxic pesticides onto the market and into operational use (USEPA 2014). Two reduced-risk herbicides, imazamox and penoxsulam, were approved by USEPA for aquatic use in 2007 and 2008, respectively. Reduced-risk pesticides have lower risk to human health or the environment (USEPA 2014). Both imazamox and penoxsulam are classified as acetolactase synthesis (ALS) –inhibiting herbicides and are members of the imidazolinone and sulfonamide families, respectively (Shaner 2014a). Both ALS inhibitors should be rotated with other modes of action to help prevent the development of resistant weeds (Richardson 2008).

The purpose of this study is to evaluate the efficacy of two reduced-risk herbicides new to the Sacramento–San Joaquin Delta, imazamox and penoxsulam, as compared to the former standard treatments with 2,4-D or glyphosate, and to assess the rates required to control waterhyacinth effectively.

Table 1. Herbicide treatments on waterhyacinth (*Eichhornia crassipes*) in Study 1 and Study 2 with the treatment number, herbicide, rate in g a.i. ha^{-1} and rate in ounces of formulation $acre^{-1}$.

Treatment number	Herbicide	Rate (g a.e. or a.i. ha^{-1})	Rate (oz. formulation $acre^{-1}$)
Study 1	Untreated Reference	0	None
	2,4-D	2,130	64
	2,4-D	1,065	32
	Glyphosate	3,363	96
	Glyphosate	1,681	48
	Imazamox	420	48
	Imazamox	210	24
	Penoxsulam	88	5
	Penoxsulam	53	3
Study 2	Untreated Reference	0	None
	Imazamox	560	64
	Imazamox	280	32
	Imazamox	140	16
	Imazamox	70	8
	Penoxsulam	98	5.6
	Penoxsulam	49	2.8
	Penoxsulam	25	1.4
	Penoxsulam	12	0.7
	Glyphosate	1,681	48

MATERIALS AND METHODS

Forty experimental floating plots, or quadrats, were constructed to contain waterhyacinth. Each quadrat was 1 m^2 (10.9 ft^2). Each plot was deployed approximately 3 m from its nearest neighbor, in eight chains of five plots each. The groups of plots were anchored in open water using cinder blocks and connected with rope. The frames were deployed to a remote backwater bay within the Delta. The experimental site was located at 38.000833°, –121.574722° off of the Old River channel. With a tidal water level fluctuation of 1.3 m, the water varied between 0.6 and 1.3 m deep. During the first study, water temperature ranged from 20.5 to 25.0 C (69 to 77 F) and air temperature ranged from 12 to 45 C. During the second study, water temperature ranged from 17.5 to 22.5 C and air temperature ranged from 10 to 45 C.

Following deployment with anchors and lines, each quadrat was planted with 20 small (approximately 15-cm diameter) rosettes of waterhyacinth collected near the site to initiate growth, covering most of the surface within the quadrat. These plants were allowed to grow for 2 wk before treatment. Treatments were randomly assigned to the quadrats.

In the first study, two rates, respectively, of 2,4-D,[1] glyphosate,[2] imazamox,[3] and penoxsulam[4] were applied (Table 1). All treatments included the surfactant[5] at a rate of 2.34 L ha^{-1} (1 qt $acre^{-1}$), or 0.25% v/v. The plots were treated 23 June 2016, using a CO_2-pressurized sprayer with a boom that had three TeeJet 11004AIXR (flat fan) nozzles running at 207 kPa (30 psi), delivering a total spray solution of 935 L ha^{-1}. Each treatment was replicated in four quadrats. On the day of treatment, two 0.1-m^2 samples of waterhyacinth per plot were taken from each of the four pretreatment plots. Pretreatment plots were assigned specifically for the purpose of collecting pretreatment biomass, and not reused in the test. Samples were dried at 70 C for 48 h and weighed for pretreatment biomass. Eight weeks after treatment, two 0.1-m^2 samples per plot were taken from all 40 plots, dried at 70 C for 48 h, and weighed for biomass (Madsen 1993a,b, Madsen et al. 1993, Madsen and Wersal 2017).

In the second study, the full label rate of glyphosate and the full, one-half, one-quarter and one-eighth label rates of imazamox and penoxsulam were used to determine an effective rate for treatment relative to the typical glyphosate treatment (Table 1). All treatments included a surfactant at a rate of 2.34 L ha^{-1}, or 0.25% v/v. The plots were treated 16 September 2016, using a CO_2-pressurized sprayer with a boom that had three TeeJet 11004AIXR (flat fan) nozzles running at 207 kPa (30 psi), delivering a total spray solution of 948 L ha^{-1}. Each treatment was replicated in four quadrats. On the day of treatment, two 0.1-m^2 samples of waterhyacinth per plot were taken from each of the four pretreatment plots. Samples were dried at 70 C for 48 h and weighed for pretreatment biomass. Eight weeks after treatment, two 0.1-m^2 samples per plot were taken from all 40 plots, dried at 70 C for 48 h, and weighed for biomass.

Statistical analysis was performed on biomass values using a one-way analysis of variance (ANOVA) with a post-hoc comparison of means at the $P = 0.05$ level of significance, calculated using Statistix[6] version 10. For the purposes of comparison, percent control was calculated as the final biomass for each treatment relative to the untreated reference biomass.

RESULTS AND DISCUSSION

The untreated reference biomass in the first study reached over 2,000 g DW m^{-2} in approximately 10 wk of growth (Figure 1). At the time of treatment, biomass was approximately 50% of this level, at 1,050 g DW m^{-2}. All treatments (2,4-D, glyphosate, imazamox, and penoxsulam) significantly reduced biomass relative to the 8-WAT untreated reference, consistent with results obtained in other studies (Van et al. 1986, Madsen et al. 1995, Wersal and Madsen 2010). Efficacy with 2,4-D was 49% control at the lower rate and 82% control at the high rate, which is consistent with previous studies with 2,4-D (Madsen et al. 1995, Datta and Mahapatra 2015). Glyphosate was not significantly better than 2,4-D, with 67% control at the low rate and 87% at the high rate. Glyphosate has been shown to be effective on waterhyacinth in numerous studies around the world (Van et al. 1986, Lopez et al. 1993, Madsen et al. 1995, Yirefu and Zekarias 2009, Datta and Mahapatra 2015). Imazamox control efficacy was 81% at the low rate and 93% at the higher rate. Imazamox was previously shown to be effective on waterhyacinth, as well as other species (Emerine et al. 2010). Penoxsulam was very effective at the rates used in the study. Control efficacy was not different at the lower (95%) and higher (94%) rates. Treatment with penoxsulam at 53 g a.e. ha^{-1} was as effective or more effective than all other treatments, even though the amount

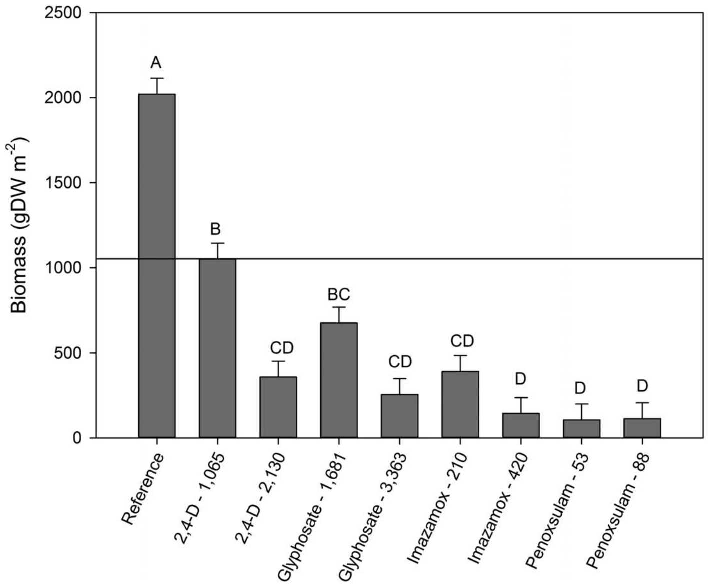

Figure 1. Biomass of waterhyacinth in the Sacramento/San Joaquin Delta 8 wk after treatment with 2,4-D (1,065 and 2,130 g a.e. ha^{-1}), glyphosate (1,681 and 3,363 g a.i. ha^{-1}), imazamox (210 and 420 g a.e. ha^{-1}), and penoxsulam (53 and 88 g a.i. ha^{-1}) versus an untreated reference. Each treatment was replicated four times. The horizontal line represents the mean pretreatment biomass of 1,050 g DW m^{-2}. Error bars above each mean represent +1 standard error of the mean. The treatments are significantly different based on a one-way analysis of variance (ANOVA, $P < 0.0001$). Means with the same letter are not significantly different at the $P = 0.05$ level based on a Bonferroni post hoc comparison of the means.

of active ingredient used (comparing g a.e. ha^{-1}) were 99 to 91% less than all other herbicides used in this trial. Reduction of herbicide load into the environment is a consideration just as important as cost for waterhyacinth management in the Delta. One of the stated goals of the management program is to reduce the loading rates of pesticides into the Delta, and this goal can be achieved in part by changing active ingredients. Penoxsulam has been shown to be effective as a foliar herbicide on waterhyacinth in a previous study (Wersal and Madsen 2010).

In the second study, the biomass at the time of treatment was 488 g DW m^{-2}. Final biomass in the untreated reference was not as high as in the first study, at 745 g DW m^{-2}, because it was later in the growing season, with lower water temperatures (Figure 2). Glyphosate was used at a rate comparable to that used in operational management (1,681 g a.e. ha^{-1}), as a comparison (e.g., positive control) to four rates of imazamox (70, 140, 280, and 560 g a.i. ha^{-1}) and four rates of penoxsulam (12, 25, 49, and 98 g a.i. ha^{-1}). The standard glyphosate reference treatment did not significantly reduce biomass relative to the untreated reference. A study by Van et al. (1986) observed 65% control with their lowest rate (1.7 kg a.e. ha^{-1}). The two lowest rates of imazamox and the lower rate of penoxsulam did not reduce biomass significantly. However, the highest two rates of imazamox and the highest three rates of penoxsulam all significantly reduced biomass relative to the untreated reference. The highest rate of imazamox yielded 96% control, and the highest rate of penoxsulam yielded 98% control. Emerine et al. (2010) tested imazamox (560 g a.e.

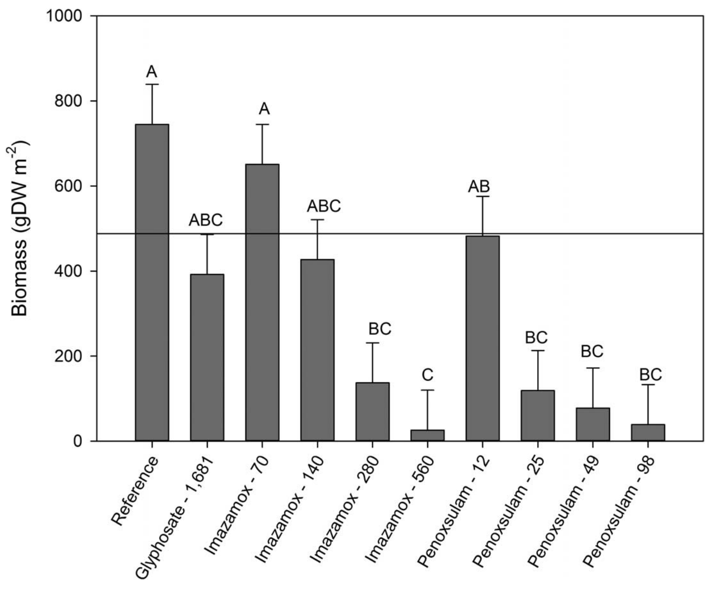

Figure 2. Biomass of waterhyacinth (*Eichhornia crassipes*) in the Sacramento/San Joaquin Delta 8 wk after treatment with glyphosate (1,681 g a.e. ha^{-1}) as the standard comparison, imazamox at four rates (70, 140, 280, and 560 g a.e. ha^{-1}), and penoxsulam at four rates (12, 25, 49, and 98 g a.i. ha^{-1}) versus an untreated reference. Each treatment was replicated four times. The horizontal line represents the mean pretreatment biomass of 488 g DW m^{-2}. Error bars above each mean represent +1 standard error of the mean. The treatments are significantly different based on a one-way analysis of variance (ANOVA, $P < 0.0001$). Means with the same letter are not significantly different at the $P = 0.05$ level based on a Bonferroni post hoc comparison of the means.

ha^{-1}) on waterhyacinth, resulting in 94% control, consistent with this study. Mudge and Netherland (2015) tested imazamox (70 g a.e. ha^{-1}) and penoxsulam (35 g a.i. ha^{-1}), resulting in 55% control of waterhyacinth for each. Wersal and Madsen (2010) applied penoxsulam to waterhyacinth at rates of 24.5, 49.1, and 98.2 g a.i. ha^{-1}, resulting in 90 to 100% control, consistent with this study.

Operationally, transitioning to imazamox or penoxsulam as a supplement to or as a replacement for glyphosate and 2,4-D would not be at the sacrifice of operational effectiveness. Either of the replacements would provide control as good as or better than the current herbicides used. The two other issues to consider are regulatory restrictions and cost. The current treatment restrictions are the result of environmental concerns for exposure and toxicity to endangered species, residue levels for irrigation water drawn from the Delta, and exposure to adjacent croplands. Currently, 2,4-D is restricted to treatments between June 15 and September 15, to minimize exposure of salmonids (*Oncorhyncus* spp.) and delta smelt. Glyphosate does not have this restriction, so operational control with glyphosate can begin on 1 March of each year. The restrictions on imazamox and penoxsulam use are as yet unknown regarding endangered species protection, but would likely be similar to those for glyphosate. Some applications of 2,4-D are restricted because of concerns with drift to crops on adjacent fields, as dictated by county agricultural commissioners. Those restrictions are not currently associated with the other three herbicides. Lastly, some treatments are curtailed by irrigation water withdrawal for croplands throughout the Delta. These are concerns for 2,4-D (for crop damage) and penoxsulam (regarding residue levels allowed in irrigation water according to the USEPA label), but not glyphosate or imazamox.

The potential for herbicide resistance is another area of concern with the use of imazamox and penoxsulam. Both of these are ALS inhibitors, which have a higher rate of herbicide resistance than 5-enolpyruvylshikimate-3-phosphate– (EPSP) synthase inhibitors (like glyphosate) or synthetic auxins (like 2,4-D). Although the selection for herbicide resistance in glyphosate-treated populations has been widely reported, only 37 species have been documented to be resistant to glyphosate and 34 species to synthetic auxins, whereas 159 species are documented to be resistant to ALS inhibitors (Heap 2017). The emergence of resistance to ALS inhibitors is more rapid than resistance to other modes of action (Tranel and Wright 2002). In 50 yr of intensive use, only 26 species resistant to synthetic auxins, or 0.5 species yr^{-1}, were identified by 2002. In 10 yr of use as part of a glyphosate-resistant crop management tool, about five species were identified as resistant to glyphosate by 2005, or 0.5 species yr^{-1}. In contrast, in 25 yr of use, 70 species were identified as resistant to ALS inhibitors by 2005, or 2.8 species yr^{-1} (Heap 2002, cited in Tranel and Wright 2002). The current focus on the need for herbicide resistance management arose from the adoption of ALS inhibitors and the resulting increase in resistant weeds (Shaner 2014b). Although it is important to rotate modes of action in weed management, it is also important to have a diversity of weed management approaches to complement management with herbicides, in an integrated pest management approach (Green 2007, Norsworthy et al. 2012, Shaner 2014b). Although some may argue that resistance in waterhyacinth is unlikely (or impossible), since its reproduction is predominantly vegetative, the selection of a somatic mutation has been documented to impart fluridone resistance in an asexual population of hydrilla (*Hydrilla verticillata* (L.) Michx.) in Florida. (Michel et al. 2004, Puri et al. 2007).

Rather than consider imazamox and penoxsulam as replacements for 2,4-D and glyphosate, they should be considered as complements within a rotation of herbicide modes of action used to control waterhyacinth in the Delta. In addition, other herbicides should be investigated and added as potential tools in these ecologically sensitive waters, particularly herbicides considered by the USEPA as reduced risk, such as carfentrazone-ethyl, florpyrauxifen-benzyl, bispyribac-sodium, and potentially others through the EPA Reduced Risk Pesticide Program (Fishel 2016).

SOURCES OF MATERIALS

[1]NuFarm Weedar 64 Broadleaf Herbcide 11901 S Austin Avenue Alsip, IL 60803.

[2]Glyphosate, RoundUp Custom, Monsanto Company, St. Louis, MO 63167.

[3]Imazamox, Clearcast Herbicide, SePRO Corporation, Carmel, IN 46032.

[4]Penoxsulam, Galleon SC Herbicide, SePRO Corporation, Carmel, IN 46032.

[5]Agri-Dex, Helena Chemical Company, Collierville, TN 38017.

[6]Statistix 10, Analytical Software, Tallahassee, FL 32312.

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