SPARTINA PROGRAM

A REVIEW OF PROGRESS AND ACCOMPLISHMENTS TO DATE

B.C. SPARTINA Working Group

protecting our shorelines

April 25, 2019

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On Behalf Of

The British Columbia Spartina Working Group

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EXECUTIVE SUMMARY

Spartina species (*anglica, alterniflora, densiflora, patens*) are invasive aquatic intertidal cord grasses on the Pacific Coast of Canada that modify natural tidal mudflats. Over a relatively short period of time (measured in years), these naturally sloping areas can be transformed into elevated Spartina meadows with a steep seaward edge. As a result, water circulation patterns change (increasing the risk of flooding), mudflats are converted into monotypic grass stands (resulting in loss of migratory bird and salmon habitat, as well as loss of economically important shellfish) and navigation channels may be altered. Since the 1980's, Spartina plants have expanded northward from the United States of California, Oregon and Washington. The BC Spartina Working Group (BC SWG) formed in 2004 to employ early detection and rapid response methods to eradicate Spartina. The BC SWG includes members of government and non-government organizations representing a diversity of responsibilities including environment, migratory birds, habitat restoration, and public use. In addition, the team liaisons with San Francisco Estuary Spartina Project and the Washington State Department of Agriculture, which are two U.S. agencies involved in Spartina eradication along the Pacific Coast.

For more than a decade Spartina control work in BC, led by the BC SWG, only used digging and excavation to control *S. anglica* and was not able to achieve containment. Since its inception, the BC SWG has coordinated over $3.6 million dollars of cash and in-kind contributions towards the eradication of Spartina from BC's shores. To date, Spartina species cover approximately 24 ha spread over approximately 1047 ha. Two Pesticide Use Permits (PUP) have been granted to control invasive Spartina species on BC's coast since 2013. Herbicide treatment of *S. anglica* and *S. patens* in the Lower Mainland has been extremely successful. The abundance of *S. anglica* infestations have reduced by approximately 65% since 2015. *S. densiflora* in Baynes' Sound has responded well to repeated manual and mechanical removal with abundance dropping by approximately 85% over the same period. The number of all species of Spartina plants combined has dropped from over 30,000 to approximately 9600 between 2015 and 2018.

Because of these successes in controlling and reducing *S. anglica* and *S. densiflora* populations through an integrated pest management approach, the impacted area of all Spartina species combined has decreased by approximately 152 ha between 2015 and 2018. Despite the dramatic reductions in *S. anglica* and *S. densiflora* species, *S. patens* has increased its impacted area by 60 ha and doubled in abundance. This is due to increased surveillance for this species, its invasive properties, and resistance from some stakeholders to use herbicide treatments. With containment and reduction of *S. anglica* and *S. densiflora* populations, the BC SWG has focused on improving coordination and detection across species for the Spartina program to be more consistent across regions and repeatable for tracking over time. *S. patens* infestations pose a challenge to traditional mapping methods and non-herbicide control techniques, such as manual digging, as *S. patens* does not grow in tufts, but grows in a dense mat. Herbicide treatment of *S. patens* should continue to be used as the primary means of control in the Lower Mainland following the successes of this method to date. It is recommended that the working group pursue *S. patens* herbicide control on Sandy Island and the Seal Islets, Hornby Island and the East Coast of Vancouver Island as a primary means of containment and population suppression. With no *S. patens* detected on Denman Island to date, and with dedicated local agencies and volunteers to monitor for this species, Denman Island is not included in the proposed PUP Boundary for the period of 2019 to 22. This decision has been made under the agreement that these groups would immediately notify the BC SWG and deploy manual control techniques to reduce and eradicate *S. patens* from Denman Island shores before the site became too large and would require herbicide.

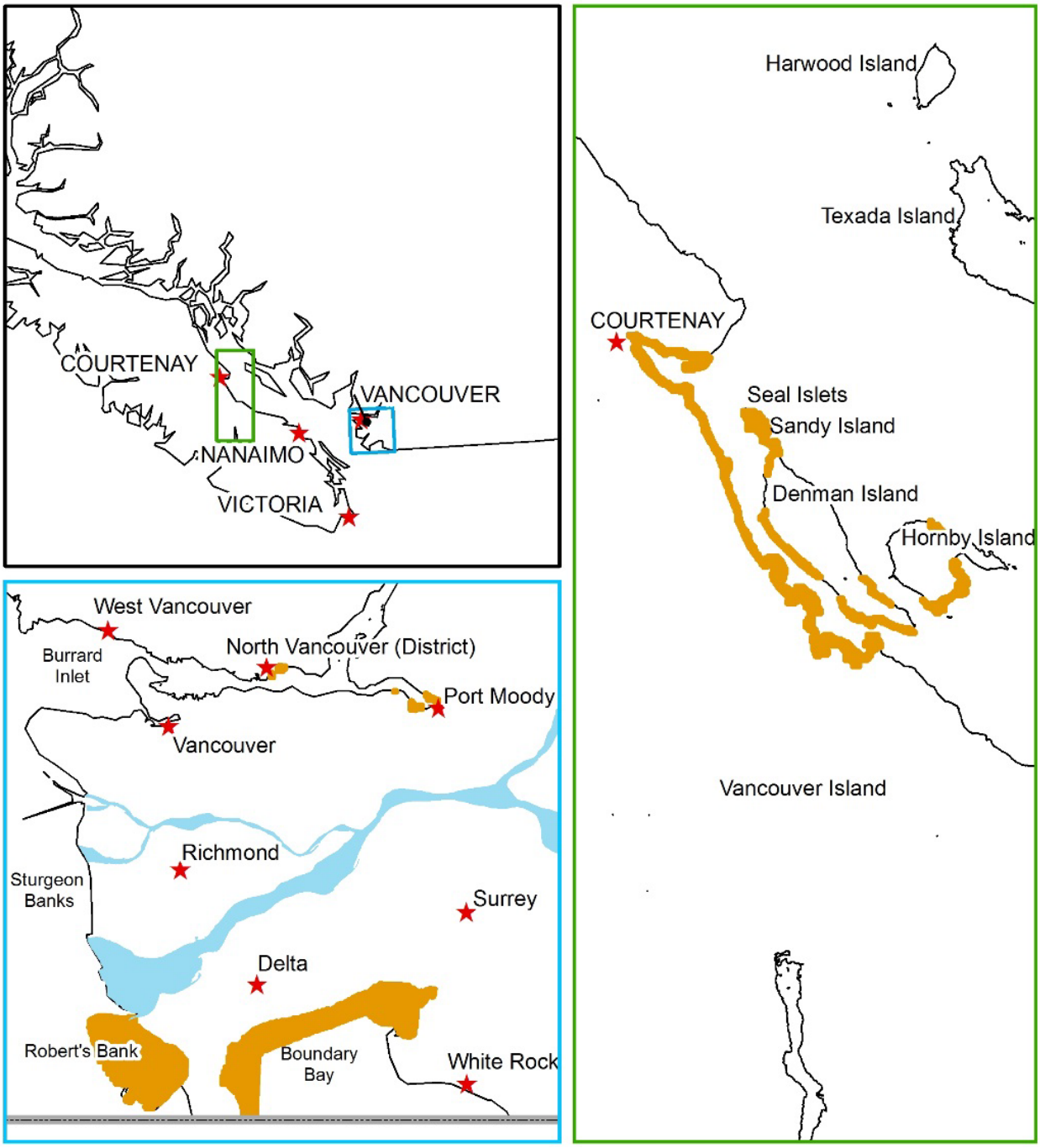

Figure 1 General location where Spartina is found throughout British Columbia. Blue represents the Lower Mainland and green represents Baynes' Sound. The approximate distribution of Spartina is shown in orange.

BACKGROUND

For more than a decade Spartina control work in BC on *S. anglica* using only mechanical/manual removal was not able to achieve containment. Therefore, since 2010, a small sub-group of the BC Spartina Working Group has worked with staff from provincial and federal Canadian agencies to determine the requirements and process to use herbicide as a control activity on Spartina. The sub-group evaluated the ecological impacts and best management information based on the success of using two herbicides to control Spartina in the United States (Washington, Oregon and California). It was determined that herbicide use in BC would require Emergency Use Registrations (EUR)of the herbicides with Health Canada's Pest Management Regulatory Agency (PMRA) as well as Pesticide Use Permits (PUP) from the BC Ministry of Environment (ENV).

The BC Ministries of Forests, Lands and Natural Resource Operations (FLNR) and ENV Environmental Sustainability section, as members of the BC SWG, jointly submitted EUR applications to the PMRA in February 2012 for the use of two herbicides to control Spartina: Rodeo (active ingredient glyphosate) and Habitat (active ingredient imazapyr) along with supplementary documentation including the proposed methods, evaluation and monitoring process. On February 13, 2013, the PMRA granted the emergency registration of the herbicides Habitat (a.i. imazapyr) and Rodeo (a.i. glyphosate) for control of Spartina in intertidal areas of BC until December 31, 2013. The PMRA EUR requires that a new application be submitted annually. In 2013, and since that time, the decision was made to only use Habitat (a.i. imazapyr) along with the adjuvant (Ag Surf II) to control Spartina following consultation with Washington State staff and to minimize overall herbicide use. As part of the approval, PMRA identified that the Ag-Surf II is the most suitable adjuvant to be included in the herbicide mix, as it is non-ionic and will improve the herbicides adhesion to the target plant, reducing the overall amount of herbicide needed. The PMRA reviewed all the potential surfactants and adjuvants and recommended Ag-Surf II based on its low toxicity to the environment.

Two PUPs have been granted to control invasive Spartina spp. on BC's coast since 2013. In 2013, FLNR and ENV Environmental Sustainability section jointly submitted a PUP for both herbicides (Rodeo (a.i. glyphosate) and Habitat (a.i. imazapyr) to the BC ENV Integrated Pest Management section. Consultation was conducted prior to and after the submission of the PUP applications. The PUP No. 804-0004-2013/2015 was issued in June 2013 for a 3-year period ending December 2015. PUP No.138-0211-2016/2019 was issued in June 2016 ending May 2019. Follow-up reports are provided to the Section Head – Integrated Pest Management Coastal Region on or before December 31, of each calendar year as a requirement of the PUP. Use of the approved herbicides for the 2017 and 2018 season in the Boundary Bay and Roberts Bank Wildlife Management Areas was provided by the BC FLNR Regional Operations Division - South Area.

PROGRAM ACCOMPLISHMENTS

The **BC SWG has coordinated over $3.6 million dollars of cash and in-kind contributions towards the eradication of** Spartina **from BC's shores since 2004.** This includes approximately $2.1 million in capital contributions and $1.4 million in in-kind contributions. Compared to Washington state which has spent more than $1 million a year over several years to contain and eradicate invasive Spartina.

EDUCATION, OUTREACH, ENGAGEMENT AND COLLABORATION

Since the latest PUP issued in 2016, the British Columbia Spartina Working Group (BC SWG) has fostered new partnerships and implemented new technology to better track Spartina spp. along BC's coast. The BC SWG collaborative efforts with the City of Port Moody, Project Watershed, Fanny Bay Oysters, K'omoks First Nation

Guardian Watchmen, and Tsleil Waututh Nation has benefited the program by building community support and awareness as well as expanded Spartina surveillance. The BC SWG members now include:

A Rocha
British Columbia Conservation Foundation (BCCF)
City of Surrey
City of Port Moody
Coastal Invasive Species Committee (CISC)
Community Mapping Network (CMN)
Corporation of Delta
Ducks Unlimited Canada (DUC)
Environment Canada – Canadian Wildlife Service (CWS)
Ecofocus Environmental Consulting
Friends of Semiahmoo Bay Society (FOSBS)
GL Williams & Associates Ltd.
Invasive Species Council of Metro Vancouver (ISCMV)
Invasive Species Council of BC
K'omoks First Nation Guardian Watchmen
Metro Vancouver
Ministry of Environment (ENV)
Ministry of Forests, Lands, Natural Resource Operations and Rural Development (FLNRO)
Port Metro Vancouver (PMV)
Project Watershed
Tsawwassen First Nation
Tsleil-Waututh Nation
West Coast Conservation Lands Management Program (WCCLMP)

With significant annual capital contributions from the Province of British Columbia, Government of Canada, and the Port of Vancouver.

INVENTORY

METHODS

Mapping efforts have improved since methods were developed in 2008/09. Methodology now includes the use of ESRI products, *Collector* and *Survey 123*. In place of Global Positioning Systems (GPS) units, both apps are downloaded onto iPhones used by summer students, volunteers and herbicide applicators. *Survey 123* records the location and size class of Spartina denoted as: Collector provides real-time tracking of mapped and treated areas and identifies the location of Spartina recorded in *Survey 123*. These new apps reduce post-data processing associated with GPS units, improves precision of areas searched vs. not searched and **increases the ability of the BC SWG to track all** Spartina **species populations over time consistently across regions.** To effectively track and convey the status of the Spartina invasion a few different metrics are used (See Appendix II for a more detailed overview):

1. the number of plants detected;
2. the size of those plants (single seedling, clone <0.3m, clone 0.3m - 1.0m, clone > 1.0m in diameter, or 5m area of single plants);
3. the estimated leaf area (size x number of plants = ~ how many square meters a dispersed population would occupy if all Spartina plants were grouped together);
4. how much shoreline is impacted (a measure of how many 1-hectare (Ha) grid cells had one or more Spartina occurrence points); and
5. Site level reporting (a roll up of metrics 1 thru 5 at the site level; see Figure 2)

The area impacted might go down while the number of plants increases, which might indicate that the containment boundary is getting smaller and there is likely a seedbank or seed source generating many new small plants. These numbers are evaluated at the species level across the province and by region and the site level. Tracking and reporting across all these metrics gives a better indication of the species invasion status/control progress provincially while lending insights to site specific nuances.

Mapped Spartina plants represented as points

Hectare Grid Cell showing the total number of plants in each cell representing total abundance

Site Summary (site boundary shown in red)

Figure 2 Spartina invasion tracking and evaluation analyses

SPARTINA INVASION SUMMARY

After the first record of *S. anglica* in British Columbia was discovered in 2003, the British Columbia Spartina Working Group (BC SWG) formed in 2004 with the concern of Spartina spreading throughout the Fraser Delta. Although *S. patens* was identified in both Burrard Inlet and Courtenay estuary circa 1980 and *S. densiflora* was confirmed in the Baynes Sound area of Vancouver Island in 2005, consistent and rigorous monitoring of both species by BC SWG did not start until after 2014. The integration of herbicide into the Spartina control program allowed the working group to achieve containment and reduction on *S. anglica (*a priority species because it expands faster and has greater impacts in shorter timeframes) in the lower mainland. Subsequently, the working group increased Spartina inventory and control efforts on Vancouver Island through new partnerships and increased funding. **Currently approximately 34 ha of Spartina occur in BC impacting approximately 1047 ha. This decrease from the previous <50 ha in the 2015 PUP is primarily due to success of the integrated pest management treatment plan for Spartina species on BC's coast.**

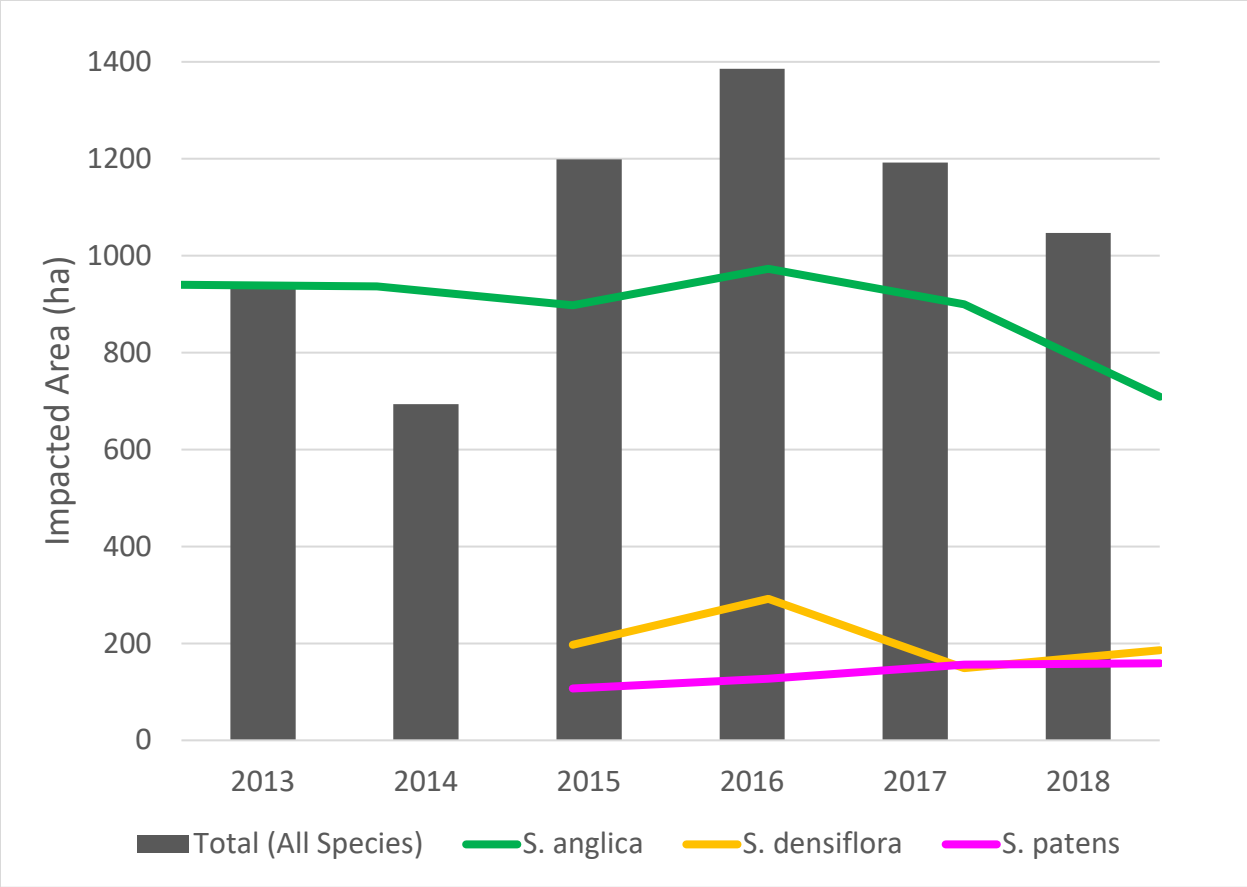

Figure 3 Spartina Summary of Impacted Area 2013 - Present

Since the program started, *S. anglica* increased annually until 2013 when the use of herbicide was introduced as a control method. Prior to 2013, removal efforts for *S. anglica* involved manual digging of clones for disposal off-site. *S. anglica* increased again in 2015 and 2016 after issues with intertidal plant harvesting permits and herbicide applications conflicted. Once timing issues were resolved, *S. anglica* leaf area in the Fraser Delta has continued to decrease into 2018 as illustrated in Figure 2. Summary of Spartina inventory metrics by species since 2013 is found in Appendix 1.

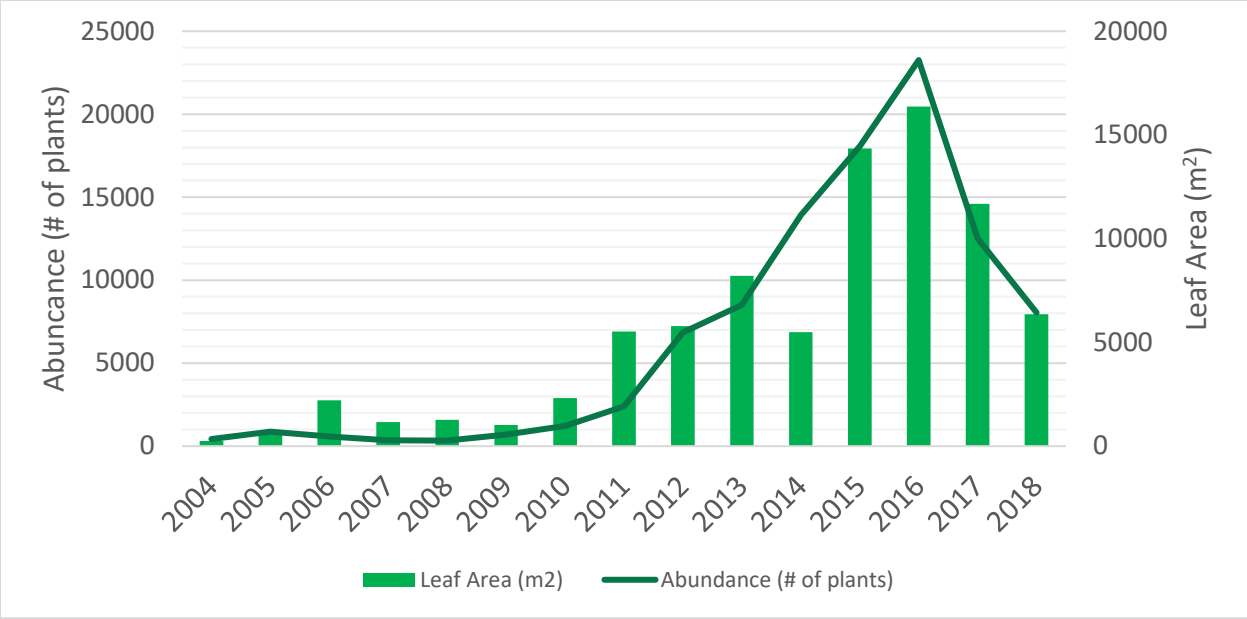

Figure 4 Number of plants and approximate leaf area of *S. anglica* in the Fraser River Delta 2004 to present

Manual removal has continued to be successful in managing *S. densiflora* as its density continues to reduce since more rigorous monitoring and removal began in 2015. **Since 2015, *S. patens* impacted area has increased by 35%, and the total number of plants has increased by 50%.** In 2017 a concerted effort was made by the BC SWG to try manually removing the *S. patens* in Baynes' Sound at an operational scale with limited success and high financial costs. **Despite > 66, 000 lbs. of *S. patens* being removed by hand, the total impacted area and number of plants has not decreased**, the shoreline topography has been altered at dig sites and *S. patens* has re-established at most sites. It is predicted that *S. patens* will continue to invade BC salt marshes if current manual removal methods are continued.

CONTROL

Reduction in abundance of Spartina *spp.*

The number of *S. anglica* plants have reduced by approximately 65% since the integration of herbicide to the control program**. *S. densiflora* has responded well to repeated manual and mechanical removal, with the number of plants dropping by 85% since the 2015.** The best available science indicates that herbicide is also effective at *S. densiflora* control; this PUP application is proposing to keep *S. densiflora* as eligible for herbicide treatment should a demonstrated need arise. One example of how the need for herbicide on *S. densiflora* might be demonstrated is a site that has had repeated manual removals without a demonstrated reduction. The BC SWG has had limited success at best in reducing *S. patens* without the use of herbicide. In the case of *S. patens*, herbicide treatment would limit impact to adjacent vegetation because the applications are more targeted. Following herbicide application native plants tend to colonize within one year compared to digging which typically takes greater than one year for native plants to re-establish if even at all. ***S. patens* infestations pose a challenge to the non-herbicide control techniques, such as manual digging, as *S. patens* does not grow in tufts but grows in a dense mat** that eventually forms a meadow (Figure 3). To manage the spread of *S. patens*, a more than reasonable number of non-herbicide control efforts have been conducted since 2012 as outlined in Figure 4.

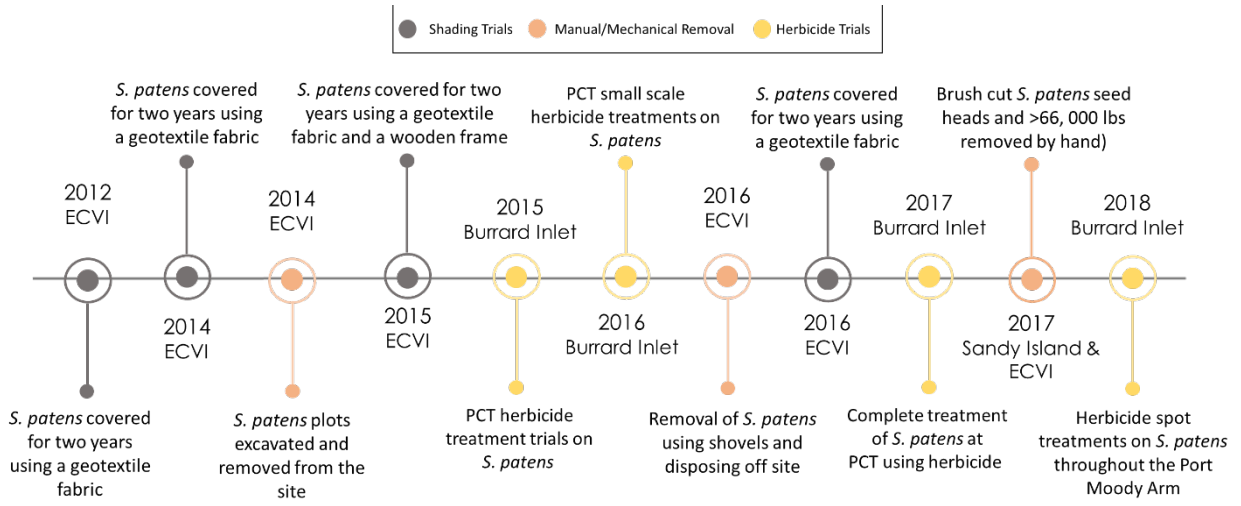

Figure 5 *S. patens* control trials since 2012. Grey represents shading trials, orange represents manual/mechanical removals and yellow represents herbicide trials.

Figure 6 Picture of *S. patens* meadow being treated with herbicide in Port Moody Arm. This picture shows how it grows into to a large meadow, too large to be dug out or shaded out. Photo credit Matt Christensen.

In the Lower Mainland and East Coast of Vancouver Island, the BC SWG experimented with shading out *S. patens* for two years using cover plots consisting of polyethylene sheeting on top of a layer of Nilex 2002 woven geotextile fabric. As of 2018, more than 25 installations of cover material ranging from 4 to 500 m^2 in size have been tried on *S. patens* in the Lower Mainland and the East Coast of Vancouver Island. Some cover trials have included combining brush cutting and steaming of *S. patens* seed heads before covering for two years. However, all the shade trials have resulted in the regrowth of *S. patens*. It is suspected that the cover plots are met with limited success because:

- They are subject to vandalism in publicly accessible areas;
- The difficulty in securing cover material to steep slopes, loose sand and rocky substrates;
- The inability to withstand the weather, animals and wave action for two-year period required unless in a protected bay;
- *S. patens* have large energy reserve in the roots causing regrowth;
- The existence of a seedbank repopulating areas after geotextiles are removed;
- The surrounding area remaining infested with *S. patens* thereby recolonizing bare areas after covers are removed.

Additional experiments using manual removal by shovels or machine excavation have been used on the East Coast of Vancouver Island but have been met with similar results. Because *S. patens* grows in the high salt marsh with a greater diversity of native plants, digging the established plant populations can significantly modify the topography and likely create collateral damage by eliminating all inter-mixed native plant populations. This damage has also been seen when removing cover plots as native vegetation is shaded out with the *S. patens* because it is a less targeted approach than herbicide. As well shore crabs (*Hemigrapsus nudus and Hemigrapsus oregonensis*) seek refuge under cover plots, digging and eroding away the shoreline further degrading the salt marsh that the Spartina program is trying to protect.

In addition to the limited success of manual and mechanical methods to control and reduce *S. patens*, the cost is higher compared to herbicide; the cost per hectare for digging, seed clipping and shading ranges from $25,000+/ha compared to ~$11,000/ha when using herbicide treatments as outlined in Table 1.

Figure 7 Single *S. patens* patch manually dug. Note the depression created in the salt marsh and the digging was likely not deep enough (due to difficulty to dig) to get all the rhizomes.

Figure 8 Garbage bags of *S. patens* piled on the shoreline to be hauled to the landfill.

Table 1 Control methods and approximate costs (Adapted from BC Spartina Response Plan, 2010)

Control Method	Approximate Cost
Digging – by hand	$123,000– $247,000/ha
Digging - Excavator	$2500 – $25,000/ha
Shading - Covering with fabric	$25,000 – $124,000/ha
Herbicide – hand pump bottle, backpack sprayer or hand pump sprayer	$11,000 / ha

Table 2 Summary of control efforts by species and year

	***S. densiflora* -**	***S. patens* -**			***S. anglica* -**	
	Digging (kg)	Removal (lb)	Shading (m^2)	Herbicide (ha)	Herbicide (ha)	Digging (# of plants)
2014	2000	* (66 m2 - volume unknown)	607	0.000	5.18	7542
2015	2000	0	81	.0012	3.88	1616
2016	7000	0	202	.3998	7.9	7220
2017	865	>29 937	202	12	4.8	20
TOTAL	11 865	>29 937	1092	16	21.8	16398

SCIENCE & EVALUATION

Adaptive treatment plans/approaches using scientific evaluation.

The BC SWG continually tracks and evaluates all control efforts to inform its annual treatment plans and approaches to effectively eradicating Spartina from BC's shores using the best available science.

After 3 years of herbicide treatments at Robert's Bank North, there was a considerable decrease in *S. anglica* detected from 0.30 hectares leaf area in 2013 to 0.07 hectares in 2016. When evaluating herbicide control at the site over the same period it was determined that despite the overall decrease in Spartina, it was still increasing in the vegetated areas (0.01 to 0.05 ha) of the site compared to mudflat areas (0.29 to 0.02 ha). This was due to an increased search effort in the vegetated zones contributing to more plants being found, distribution of Spartina within native vegetation making it more difficult to detect and the ability to effectively treat the entire plant amongst the native vegetation. As a result, the BC SWG adapted mapping and treatment methods to better target Spartina plants intermixed with native vegetation. Timing of mapping and treatment in vegetated areas was moved to late summer and early fall to make finding and treating easier because native vegetation has started to senesce while Spartina plants are still green, emerging amongst senesce vegetation and at their maximum annual growth.

In 2013, the BC SWG undertook a study to evaluate herbicide combinations that would be most effective at controlling Spartina. A monitoring study was set up in Boundary Bay consisting of eight treatments with four replicates. The experimental design included the following application rates: 1) Herbicide (Rodeo – a.i. glyphosate,

Habitat – a.i. imazapyr), both herbicides, with 2 levels for each: label rate, ½ label rate, 2) Herbicide application (foliar, wick). Based on efficacy rating observations 336 days after treatment (August 2014), all treatments except Rodeo half label rate demonstrated control on Spartina. Full label rates had the best results in terms of the best control most consistently across plots. The combination of full label rates of both Rodeo and Habitat had greater control than either one herbicide on its own however the difference was insignificant. Therefore, to reduce the number of pesticides used in the environment and following recommendations from the Washington State Spartina program, the BC SWG proceeded to treat Spartina with the recommended label rate of Habitat only.

RECOMMENDATIONS

For the 2019 PUP the BC SWG recommends;

- Continued used of the integrated control plan for *S. anglica* by manually removing single plants and small clones and using herbicide for clones greater than 0.3m in diameter
- Continued use of manual removal for *S. densiflora* and use herbicide as a last resort should a demonstrated need arise.
- A new control plan for *S. patens* that uses herbicide as the main control method for all patch sizes throughout Burrard Inlet and Vancouver Island
- Continue extensive surveys of Spartina spp. to monitor efficacy and evaluate program progress

PUP REVIEW

2019 PUP BOUNDARY

The 2019 PUP will be split in two; one for the Lower Mainland and one for Vancouver Island. The primary use of the Lower Mainland PUP will be to continue to contain and reduce *S. anglica* populations in Boundary Bay and Robert's Bank. As well the spot treatments will likely be required in Port Moody Arm, following two years of successful operational treatment of *S. patens* in Port Moody Arm. Finally, herbicide treatment is expected to begin in 2019 at Maplewood Conservation Area and continue in conjunction with monitoring and restoration activities to prevent reinvasion.

The Lower Mainland PUP boundary area will include Roberts Bank, Boundary Bay, Burrard Inlet and remaining lower mainland shoreline encompassing approximately 12 332 ha of shoreline (Figure 4). The Vancouver Island PUP boundary area will include the East Coast of Vancouver Island, Sandy Island & the Seal Islets, and Hornby Island encompassing approximately 4266 ha of shoreline (Figure 5).

Figure 9 2019 PUP boundary line for the Lower Mainland.

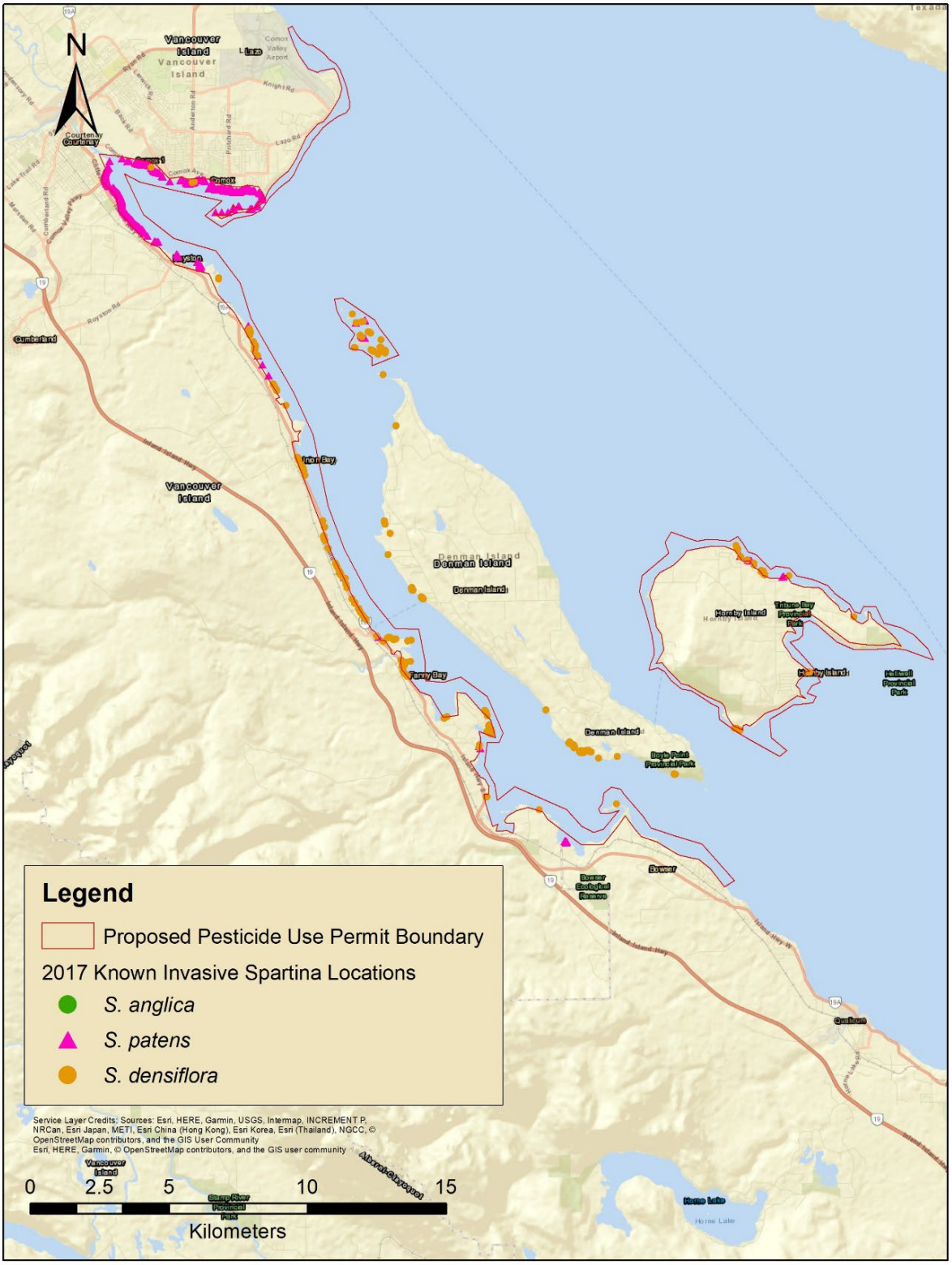

Figure 10 2019 PUP boundary line for Vancouver Island.

HERBICIDE APPLICATION

In 2013, a review of the herbicides used to eradicate Spartina in the US Pacific Coast jurisdictions revealed that the combined application of active ingredients imazapyr and glyphosate maximized efficacy in controlling Spartina.

Both herbicides are systemic in action and kill the plants to their roots, rather than other contact herbicides (e.g. diquat and endothall), which only kill the parts of the plant contacted. There is a significant amount of information and protocols on the use of imazapyr and glyphosate for Spartina already developed in the states of California, Oregon and Washington. The BC SWG has elected to use only imazapyr to minimize the quantity and volume of pesticide being used while still achieving control and population reduction. This decision was further supported by the results of Spartina herbicide treatment efficacy trials between 2013 and 2015. The BC SWG found that glyphosate did not achieve significant control at the study site to justify including it in the tank mix for Spartina herbicide treatments. To date in BC, we have only used imazapyr in an operational capacity with applications rates matching those used in Washington State and San Francisco (Table 3). Habitat P.C.P. # 30841 is the product used in association with the Emergency Use Registration granted by Health Canada's Pest Management Regulatory Agency (PMRA).

Table 1 Herbicide Formulation Used in Washington and California (Leson and Associates, 2005)

	Spray Volume	Formulation	Active Ingredient	Surfactant	Colorant
Imazapyr P.C.P. # 30841	934 L/ha	0.52-0.75% solution (.56 - .75 L/100L)	1.12 - 1.68 kg a.e./ha	0.5% v/v Ag Surf II (0.5 L/ 100 L)	8.2 L/378 L

Since the introduction of herbicide into *S. anglica* control, there has been a decrease its abundance, thereby reducing the amount of herbicide needed to maintain containment and continue to suppress the population towards eradication. Records of the amount of herbicide used on *S. anglica* throughout the Lower Mainland since 2013 are shown in Appendix 1, Table 2 and Table 3.

In 2019, a new federal EUR has been established and a new three-year provincial PUP (2019 to 22) is in the consultation phase. The 2019 PUP boundary area has increased by 5746 ha (16, 755 ha total) since the 2016 PUP (10,998 ha total), as shown in Table 1. Boundary lines in the Lower Mainland will expand in White Rock, Mud Bay/ Nicomekl Area and Burrard Inlet. This will allow BC SWG the ability to address *S. anglica and S. patens* should they appear outside of the 2016 boundary lines.

The decision to include Sandy Island, Seal Islets, and Hornby Island into the pesticide boundary line on Vancouver Island, follows several years of exhaustive efforts to find a non-herbicide means of control (i.e., cover plots, manual and mechanical) that were deemed unsuccessful.

RECOMMENDATIONS

Expand PUP Boundary to include Sandy Island, the Seal Islets and Hornby Island

- Because *S. patens* is more prevalent here than previously thought
- Limited access for manual/mechanical removal, cost and labour intensity required to be effective
- Highly active shorelines making cover plots unsuitable

Apply for two separate PUPs in the geographic regions of Vancouver Island and the Lower Mainland

- Because of the need for PUP on East Coast of Vancouver Island, engagement will be more effective

- Lower Mainland is more familiar with herbicide use and PUP process.

Table 3 PUP Boundary Area Change History

	2013	2016	2019
Total Boundary Area	2451 ha	10 998 ha	16 744 ha
Lower Mainland Boundary Size	Robert's Bank, Boundary Bay and 4 locations in Burrard Inlet. (2451 ha)	Roberts Bank, Boundary Bay, Burrard Inlet and remaining lower mainland shoreline (8820 ha)	Roberts Bank, Boundary Bay, Burrard Inlet and remaining lower mainland shoreline (12 332 ha)
Approximate Total Spartina Leaf Area	6 ha	12 ha	10 ha
East Coast Vancouver Island & Baynes' Sound Boundary Size	N/A	East Coast of Vancouver Island (2778 ha)	East Coast of Vancouver Island, Sandy Island & the Seal Islets, and Hornby Island (4266 ha)
Approximate Total Spartina Leaf Area	-	10 ha	24 ha

REFERENCES

B.C. Spartina Response Plan 2010, prepared by Environmental Dynamics; Keri Dresen, Lisa Scott and Gary Williams for Ducks Unlimited Canada. 73 pages.

Leson & Associates. 2005. Use of Imazapyr Herbicide to Control Invasive Cordgrass (Spartina spp.) in the San Francisco Estuary Water Quality, Biological Resources, and Human Health and Safety. Prepared for San Francisco Estuary Invasive Spartina Project. 55 pages

APPENDIX 1 – HERBICIDE USE ON SPARTINA TO DATE

Table 4 Amount of herbicide used to manage *S. anglica* since 2013.

500L of mix /ha	2013	2014	2015	2016	2017	2018
Litres (L) of herbicide mix used	1089.5	2595	1949.5	3744	2412	1109
Volume of Habitat Used (L)	7.51	19.46	14.62	28.08	18.09	8.32
Active Ingredient (Imazapyr) Used (kg)	1.8	4.671	3.509	6.74	4.34	1.99
Volume Surfactant Viterra Ag-Surf II (Alcohol ethoxylate) – (L)	5.01	12.97	9.7	18.72	12.06	5.54
Active Ingredient (kg)	4.61	11.937	8.9	17.23	11.1	5.10
Estimated ha	2.179	5.19	3.899	7.48	4.824	2.22

Table 5 Amount of herbicide used to manage *S. patens* since 2016.

500L of mix /ha	2016	2017	2018
Litres (L) of herbicide mix used	216	583	17
Volume of Habitat Used (L)	1.62	4.37	0.127
Active Ingredient (Imazapyr) Used (kg)	0.38	1.05	0.031
Volume Surfactant Viterra Ag-Surf II (Alcohol ethoxylate) – (L)	1.08	2.91	0.35
Active Ingredient (kg)	0.99	2.68	0.32
Estimated ha	0.432	1.46	0.034

APPENDIX 2 - SPARTINA ANALYSIS REPORTING CALCULATIONS

Ducks Unlimited Canada (DUC) leads a multi-agency partnership program that tracks three species of invasive cordgrass: *S. anglica*, *S. densiflora*, and *S. patens*. Surveyors trained to identify the three species record point observations in survey areas throughout the year. Individual Spartina observations are categorized into size classes (Table 1). The point data for each species is collated and aggregated during the next year. DUC aggregates the data in two formats of different scale: **Cell Summaries** and **Site Summaries**.

Cell Summaries are the first method of aggregation. Each IAPP site, existing or new, is divided into 100 m by 100 m cells of one hectare in area. The sum of observations for each size class is calculated for every cell on a per species basis. The estimated leaf area of a species in a cell is calculated by multiplying the total of a size class by its Areal Coefficient (Table 1) and adding the values for each size class.

Table 6 Size Classes and their Areal Coefficients

Size Class	Description	Areal Coefficient (m^2)
S	Single Plant or Seedling	0.002
A	Patch with diameter less than 30 cm	0.071
B	Patch with diameter of 30 cm to 1 m	0.785
C	Patch with diameter of 1 m to 5 m	3.14
D	Patch with diameter of approximately 5 m	19.625
M	Patch with diameter greater than 5 m	38.465

The resulting equation for the leaf area of a Spartina species in a cell is:

$$\text{Area} = (\Sigma S * 0.002) + (\Sigma A * 0.071) + (\Sigma B * 0.785) + (\Sigma C * 3.14) + (\Sigma D * 19.625) + (\Sigma M * 38.465)$$

For example, a cell with multiple *S. anglica* observations of 10 seedlings (Size S), 3 patches of a diameter of 30 cm to 1 m (Size A), 5 patches with a diameter of 1 m to 5 m) Size C, and 1 patch greater than 5 m (Size M) would have an area of 54.398 m^2.

$$\text{Area} = (10 * 0.002\ m^2) + (3 * 0.071\ m^2) + (5 * 3.14\ m^2) + (1 * 38.465\ m^2)$$
$$\text{Area} = 0.020\ m^2 + 0.213\ m^2 + 15.7\ m^2 + 38.465\ m^2$$
$$\text{Area} = 54.398\ m^2$$

Site Summaries are the format of aggregated data submitted to IAPP by DUC. These are derived from the cell summaries. For each IAPP site, the estimated leaf area (m^2) of a given species is calculated by adding the estimated leaf area of that species for all one-hectare cells within the designated IAPP site.