

Twin Harbors Waterkeeper

Dear Shawn:

Our law firm represents Twin Harbors Waterkeeper. On behalf of this organization, attached is a comment letter that provides comments on the Washington Department of Ecology's draft 2025 General National Pollutant Discharge Elimination System Permit for Managing *Zostera japonica* on Commercial Clam Beds in Willapa Bay. Please respond to the attached comment letter in writing and include the letter and its Exhibit A (also attached) in the administrative record for this matter.

Thank you,
Erica Proulx
Kampmeier & Knutsen, PLLC
705 Second Avenue, Suite 901
Seattle, Washington 98104
(206) 739-5184
erica@kampmeierknutsen.com

KAMPMEIER & KNUTSEN PLLC
ATTORNEYS AT LAW

ERICA L. PROULX
Licensed in Washington
206.739.5184
erica@kampmeierknutsen.com

January 13, 2025

Via Washington Department of Ecology Online Public Comment Form

Shawn Ultican
Washington Department of Ecology
P.O. Box 47696
Olympia, WA 98504-7696

Re: Comments on Ecology's draft 2025 General NPDES Permit for Managing *Zostera japonica* on Commercial Clam Beds in Willapa Bay

Dear Shawn:

Our law firm represents Twin Harbors Waterkeeper ("THW"). On behalf of this organization, this letter provides comments on the Washington Department of Ecology's ("Ecology") draft 2025 General National Pollutant Discharge Elimination System Permit for Managing *Zostera japonica* on Commercial Clam Beds in Willapa Bay ("the Permit"). Please respond to these comments in writing and include these comments and associated attachment in the administrative record for this matter.

THW is a 501(c)(3) non-profit organization based in southwest Washington. The mission of THW is to protect and improve water quality and marine and freshwater habitats on the Washington coast, including in Willapa Bay and Grays Harbor. THW is especially interested in the health of Willapa Bay ("the Bay"), the second largest estuary on the West Coast. Much of the Bay is protected by the Willapa National Wildlife Refuge. The refuge's abundant salt marshes and tidal mudflats, coastal dunes and beaches, grasslands, freshwater wetlands, and old-growth forests are home to many fish, wildlife, and plant species. Over 200 species of birds are documented annually in Willapa Bay, including the endangered marbled murrelet. Additionally, green sturgeon (*Acipenser medirostris*) spend the summer in Washington State coastal estuaries like Willapa Bay where they feed on burrowing shrimp. The southern distinct population segment of green sturgeon is listed as threatened under the Endangered Species Act.

Willapa Bay has suffered from infestations of invasive species due to human activity such as industrial forestry and shellfish aquaculture. Other harms to the Bay caused by industrial forestry include sedimentation and water quality degradation. Because of these and other factors, native species and the ecology of the Bay have been compromised.

Dedicated scientists work to manage invasive plants and invertebrates so that aquaculture can continue to thrive. Additionally, Washington State has expended significant resources in attempts to recover wild salmonid populations. Despite these efforts, salmonid populations and Southern Resident Killer Whales, which depend on these salmonid species, face the threat of extinction.

Although THW understands the need to balance farming the tidelands and protecting native species of the Bay, THW advocates against any actions that pose additional risks to the Bay and to the rare, sensitive, threatened, and endangered species that rely on it, including the application of herbicides such as imazamox to control *Zostera japonica* on commercial clam beds.

For these reasons, we strongly urge Ecology to strengthen the Permit in the following ways:

I. The Draft Permit’s Monitoring and Reporting Requirements Are Insufficient.

The Permit does not include sufficient reporting and monitoring requirements, resulting in a lack of transparency and accountability to Ecology and to the public. The Permit should be revised to include additional application, reporting, and monitoring requirements.

Specifically:

- The Permit requires the following submittals: (1) a Discharge Management Plan (“DMP”) once per coverage or update; (2) an annual pre-treatment plan; and (3) an annual post-treatment report. *See* p. 1, Table 1. Only “as necessary” are permittees required to submit notices of noncompliance or spill. *Id.*

In addition to these submittals, the Permit should be revised to require monthly reporting on compliance with (or non-applicability of) Special Condition S3, S4, and S5 requirements during the permissible imazamox application window (currently May through July) regardless of whether treatment has occurred or is planned. Such reporting should be made available to the public through Ecology’s Permitting and Reporting Information System (“PARIS”).

This reporting should include, but is not limited to:

- Proof that application does not cause or contribute to violations of Water Quality Standards, Groundwater Quality Standards, Sediment Management Standards, and human health criteria in the National Toxics Rule. *See* Special Condition S3.A, pp. 6–7.
- Proof that permittees use All Known, Available, and Reasonable methods of prevention, control, and Treatment (“AKART”), including compliance with the Washington Pesticide Control Act, Washington Pesticide Application Act, Federal Insecticide, Fungicide, and Rodenticide Act, and product labels. *See* Special Condition S3.A and pp. 6–7; *see also* Special Condition S4.

- Proof of compliance with WAC 173-201A-410. *See* Special Condition S3.B, p. 7.
- Proof that treatment does not cause or contribute to further impairment of Willapa Bay for any parameter for which Willapa Bay is listed as impaired. *See* Special Condition S3.C, p.7.
- Proof that treatment does not cause harm to sensitive, threatened, or endangered animal species or rare plant populations. *See* Special Condition S3.D, pp. 7–8. This should include monitoring of and reporting on what species interact with the area before, during, and after application of imazamox.
- Proof of compliance with permittee’s DMP. *See* Special Condition S3.E, p. 8.
- Proof of compliance with the product label and all pesticide application requirements mandated by Special Condition S4.A, pp. 8–10.
- Proof that permittee has maintained the required buffer per Special Condition S4.B, including photographic evidence. *See* p. 10.
- Proof that permittee has complied with the posting requirements of Special Condition S4.D, including photographic evidence. *See* p. 10.
- Sample results from a laboratory registered or accredited under Chapter 173-50 WAC, including the following parameters:
 - Date, place, and time of sampling;
 - Date and time of sample analyses;
 - Who performed the analyses;
 - Analytical techniques and methods used;
 - Results of analyses;
 - Flow;
 - Temperature;
 - Settleable solids;
 - Conductivity;
 - pH; and
 - Turbidity

See Special Condition S5, pp. 11–12.

- Proof that permittee has measured the buffer distance in compliance with Special Condition S5.A, including reporting on any *Zostera* plants affected by treatment beyond the parcel boundary.
 - Photographs required by Special Condition S5.A should be made available to the public.

See p. 12.

In addition to requiring more detailed and more frequent reporting, and making such reporting available to the public through PARIS, THW urges Ecology to make the following Permit revisions:

- Special Condition S2.C.3 (pp. 3–4) provides that “[p]ermittees renewing their permit coverage are not required to publish a public notice.” Public notice should be required for first-time applicants, existing permittees applying to modify permit coverage, *and* for

permit renewals. Thus, THW requests a revision to Special Condition S2.C.3(c) to require public notice so that the public, including organizations like THW, can review permittee's compliance with their current permit and comment prior to Ecology issuing a renewal.

- Proposed revisions and additions for Special Condition S4.A:
 - Informed by what is necessary to protect Willapa Bay from harmful water quality impacts, Special Condition S4.A should specify what spray equipment is permissible for application and what equipment is prohibited.
 - THW attended Ecology's in-person public workshop and hearing on January 7, 2025, at the Willapa Harbor Community Center. There, THW learned that backpack sprayers are required for application of imazamox. This should be specified in the Permit. Additionally, the Permit should specify how applicators are permitted to access the spraying zone and whether application must be done on foot. THW strongly urges Ecology to revise the Permit to prohibit the use of vehicles to assist in the spraying process.
 - Special Condition S4.A.2(e) (p. 9) should be revised to shorten the application window to when application is likely to be most effective, ending in early June. See Kim D. Patten, *Imazamox Control of Invasive Japanese Eelgrass (Zostera japonica): Efficacy and Nontarget Impacts*, 53 J. Aquatic Plant Mgmt. 185–90, 189 (2015) (attached as Exhibit A).
 - Special Condition S4.A.2(g) (p. 9) should require more than one hour of dry time before tidal inundation. THW proposes six hours of dry time. Additionally, the area should be monitored during the dry time.
 - Special Condition S4.A.2(i) should describe how wind speed must be measured or, in the alternative, require permittees to report on how wind speed was measured and when it was measured relative to application.
 - Currently, Special Condition S4.A.2(j) (p. 10) prohibits application of imazamox directly into drainages that contain *Z. marina* and move water off the treatment site. In order to avoid harm to *Z. marina*, please require that no spraying be allowed near or over pools where it exists and require that no spray be allowed near drainage swales that contain *Z. marina*.
 - As described above, permittees should be required to report on compliance with these and all other parameters in monthly and annual reporting.
- Special Condition S4.B (p. 10) requires a minimum buffer width of 10 meters for all treatment sites. Please require markers such as food-grade dye or flags to mark boundaries and the buffer area.
- In addition, Special Condition S4.B should require exact monitoring requirements to ensure the buffer is protective of adjacent vegetation. THW suggests vegetation plots in the buffer to measure for *zostera spp.* plant kill every 250 feet in the buffer one week

after herbicide application. The results of this monitoring should be a required component of monthly and annual reporting.

- Special Condition S4.D (p. 10) requires permittees to post signs near the treatment site 24 hours prior to treatment. However, most of the treatment sites are not accessible to the public, so there is no way (1) for the public to see the postings and be informed of treatment or (2) to ensure that permittees comply with the posting requirements. Please revise the permit to require signs posted four business days prior to treatment at and around Leadbetter Point, including near and around Leadbetter Point State Park and the Willapa National Wildlife Refuge. In addition to what the draft site signage template already requires (treatment dates, applicator contact information, and permit number), these postings should include:
 - The location of application, including both a written description and a map;
 - The amount of imazamox to be applied;
 - The number of acres to be treated; and
 - Name and contact information of commercial clam bed owner/operator
- Currently, the Permit merely requires the permittee to conduct monitoring and retain records to be made available to Ecology upon request. *See* pp. 11–13. As detailed above, the Permit should instead require permittees to submit Special Condition S5 monitoring (pp. 11–12) to Ecology once per month during the permissible treatment window regardless of whether treatment has occurred or is planned. Such reports should then be made available to the public on PARIS.
- Special Condition S7.B (pp. 13–14) requires permittees to provide notice to Ecology and adjacent landowners “at least 10 days prior to each herbicide treatment.” In addition, the notification forms (Ecology Pre-Treatment Notification Form and Landowner Pre-Treatment Notice) should be publicly posted online.

II. The Draft Permit Fails to Ensure Compliance and Accountability.

THW is concerned about current and future compliance with the Permit. Based on information publicly available, it appears Ecology has never inspected or taken any enforcement actions against permit holders.

To address these concerns, THW requests the following information and proposes the following changes to the Permit:

Fact Sheet and Reporting on Past Compliance and Ecology Action:

The Permit’s Fact Sheet should detail whether the nine current permit holders have complied with and are in continued compliance with the Permit, including all Special Condition S3, S4, and S5 requirements.

For example:

- Were all applications of imazamox directly supervised by a properly licensed applicator?
- Was all equipment properly calibrated and maintained?
- Were application rates less than 1.4 ounces per acre?
- Did permittees refrain from applying other pesticides to commercial clam beds four days before and after imazamox application?
- Did permittees refrain from applying imazamox unless and until *Z. japonica* levels met or exceeded DMP action thresholds?
- Did permittees allow at least one hour of dry time before tidal inundation?
- Did permittees refrain from application when wind speeds exceeded 10 miles per hour and how was this measured?
- Etc.

If this change is not made, can Ecology please provide this information in response to these comments?

Additionally, the Permit's Fact Sheet should summarize any and all Ecology enforcement actions and inspections under the Permit to date. If this change is not made, can Ecology please provide this information in response to these comments?

Reporting on Compliance with Special Conditions S3 and S4:

As aforementioned, the Permit prohibits violation of Water Quality Standards and requires permittees to use AKART. *See* Special Condition S3.A and pp. 6–7; *see also* Special Condition S4. However, the draft Permit fails to provide any means of ensuring or enforcing compliance with these requirements.

Similarly, the Permit “prohibits treatment that causes oxygen depletion to the point of stress or lethality to aquatic biota from plant die-off, the mortality of aquatic vertebrates, or unintended impacts to water quality or biota”; prohibits application of active ingredient imazamox at a rate of more than 1.4 ounces per acre; and prohibits aerial application, among other requirements and limitations. *See* Special Condition S4, pp. 8–10.

Rather than one annual report, the Permit should require permittees to submit monthly reporting during the permissible treatment window, made available to the public via PARIS, regarding compliance with Special Conditions S3 and S4. Reporting should be required even if no treatment has occurred or is planned.

Inspection:

General Condition G3 gives Ecology the right of entry. *See* p. 18. Instead, Ecology should proactively conduct regular inspections.

Since permittees can only apply imazamox once per year (*see* Special Condition S4.A.2(f), p. 9), and given that there are currently only nine permittees, THW proposes that Ecology conduct two inspections per permittee each year during the permissible treatment

window. One inspection should occur prior to planned treatment and one should occur following treatment. Inspection reports should be made available to the public thirty days following inspection.

THW proposes adding these requirements to Special Condition S5 while leaving General Condition G3 intact.

If Ecology declines to make these revisions, can Ecology please explain, in response to these comments, how it ensures compliance with the Permit?

Who Is Liable?

The draft Permit fails to make clear who is liable for compliance with the Permit.

Special Condition S2.A notes that “[c]overage under this permit is for pesticide applicators . . . and their **Sponsors** who specifically want to use imazamox to control *Z. japonica* within commercial clam beds in Willapa Bay.” See p. 2. The Permit defines “applicant” as “[t]he WSDA-licensed Pesticide Applicator with an aquatic pest control category endorsement and their Sponsor applying for permit coverage”; “permittee” as “[a]ny WSDA licensed Pesticide Applicator with an aquatic pest control category endorsement having coverage under this permit”; and “sponsor” as “[a]n individual or entity in the business of commercial production and sale of clams that has the legal authority to decide to apply herbicide to its owned or leased commercial clam beds.” See pp. 24, 26, 27. The nine current permitholders listed in PARIS are all shellfish growers.

The Permit should make clear that it is the entities in the business of commercial production and sale of clams—i.e., the owners/operators of the permitted facility—that are the permit holders liable for compliance. This aligns with other Ecology NPDES permits where the owner/operator of the discharging facility is liable for permit violations not, for example, third parties hired to help with facility management or permit compliance.

Specifically, THW proposes the following revisions:

- Special Condition S2.A should state: “Coverage under this permit is for individuals or entities in the business of commercial production or sale of clams that have the legal authority to decide to apply herbicide to owned or leased commercial clam beds and want to use imazamox to control *Z. japonica* within commercial clam beds in Willapa Bay (“Permittees”). Coverage under this permit must be obtained before imazamox treatment begins. Permittees are required to apply with a pesticide applicator licensed by the Washington State Department of Agriculture with an aquatic pest control category endorsement (“Sponsors”).”
- Applicant should be defined as: “The individual or entity in the business of commercial production or sale of clams applying for permit coverage and the WSDA-licensed Pesticide Applicator with an aquatic pest control category endorsement acting as their Sponsor.”

- Permittee should be defined as: “An individual or entity in the business of commercial production and sale of clams that has the legal authority to decide to apply herbicide to its owned or leased commercial clam beds.”
- Sponsor should be defined as: “Any WSDA-licensed Pesticide Applicator with an aquatic pest control category endorsement applying with a Permittee under this Permit.”
- Changes should be made throughout the Permit to reflect these revisions (e.g., current uses of “permittee” to describe pesticide applicators should be changed to “sponsor,” and current uses of “sponsor” to describe clam bed owners/operators should be changed to “permittee”).

If Ecology declines to make these revisions, can Ecology please respond to these comments by specifying which party is liable for noncompliance with the Permit?

III. Experimental Use Should Not Be Permitted Under this Permit.

Special Condition S1.A provides that “[p]ermittees may apply chemicals not listed in this permit on a limited basis in the context of a research and development effort under the jurisdiction of the Washington State Department of Agriculture by obtaining a Washington State Experimental Use Permit.” *See* p. 2. Special Condition S4.E provides that “[e]xperimental use of chemicals not listed in this permit may occur on a limited basis in the context of a research and development efforts [sic] related to the chemical control of *Z. japonica*.” *See* p. 11.

The experimental use of chemicals should not be allowed under this Permit. Washington State and Federal experimental use permits are not NPDES permits and there is no notice or opportunity under this Permit for the public to participate and ensure that such chemicals do not harm Willapa Bay. Moreover, the Permit does not provide limits or assurances that these experimental chemicals will not cause harm beyond the scope of the Permit.

While THW proposes elimination of these provisions, at a minimum, the Permit should require permittees to report any experimental use and related permits in their application, modification, and renewal materials, giving the public an opportunity to comment on the use of experimental chemicals to control *Z. japonica* in Willapa Bay. Permittees should also be required to report the use of any experimental chemicals in their monthly and annual reports with citations to their experimental use permits.

If Ecology declines to adopt these changes, can Ecology please explain, in response to these comments, why it believes the Permit should allow experimental uses and how these Permit provisions ensure (1) no harm to Willapa Bay and (2) the public’s right to be informed and to comment on the use of experimental chemicals in Willapa Bay to control *Z. japonica*?

IV. Conclusion.

Twin Harbors Waterkeeper is concerned that Ecology’s Permit, as written, fails to sufficiently protect Willapa Bay and the species that rely on it. Please consider the concerns and suggested revisions expressed in these comments. Please also explain how the current and draft

Permits are effective in regulating imazamox applications, holding permit holders accountable for compliance, keeping the public informed, and protecting Willapa Bay. Please respond to these comments in writing so our clients and others can understand Ecology's views on these issues, and please include these comments and all attachments in the administrative record for this matter.

We appreciate the opportunity to comment on the draft 2025 *Zostera japonica* Management on Commercial Clam Beds in Willapa Bay General Permit. THW supports Ecology's efforts to regulate imazamox. However, the Permit must include stronger mechanisms for permittee accountability, Ecology inspection and enforcement, and public reporting and transparency.

Thank you for taking the time to review and respond to these comments and questions. Please notify me and Twin Harbors Waterkeeper in writing of any subsequent action on this Permit. Please also contact me with any questions or concerns about these comments or to meet with me or my clients to discuss them. You can reach me at the phone number or email address listed in the letterhead or by mail at Kampmeier & Knutsen PLLC, 705 Second Avenue, Suite 901, Seattle, Washington 98104.

Sincerely,

KAMPMEIER & KNUTSEN, PLLC

By: s/ Erica L. Proulx
Erica L. Proulx

cc. Sue Joerger and Lee First, Twin Harbors Waterkeeper

EXHIBIT A

See discussions, stats, and author profiles for this publication at: <https://www.researchgate.net/publication/282380598>

Imazamox control of invasive Japanese eelgrass (*Zostera japonica*): Efficacy and nontarget impacts

Article in *Journal of Aquatic Plant Management* · July 2015

CITATIONS

3

READS

222

1 author:



[Kim Patten](#)

Washington State University

62 PUBLICATIONS 804 CITATIONS

SEE PROFILE

Imazamox control of invasive Japanese eelgrass (*Zostera japonica*): Efficacy and nontarget impacts

KIM D. PATTEN*

ABSTRACT

The nonnative eelgrass, Japanese eelgrass (*Zostera japonica* Asch. & Graebn) has infested several West Coast estuaries in North America. In Willapa Bay, WA, coverage has expanded enough to result in deleterious impacts on commercial shellfish production. Research on foliar and subsurface applications of the herbicide imazamox was conducted using replicated field trials to assess the efficacy for control of Japanese eelgrass and potential nontarget effects to the native eelgrass, (*Zostera marina* L.) and several macroalgae species. Foliar applications of imazamox controlled established Japanese eelgrass with or without surfactant, across a range of rates, from 0.03 to 0.84 kg ai ha⁻¹. Control of Japanese eelgrass seedlings was obtained with rates as low as 0.02 kg ai ha⁻¹ imazamox. Best efficacy was obtained when tidal waters fully drained off the site, and the eelgrass canopy was dry. When Japanese eelgrass had a thin, protective layer of tidal water over it, rates of imazamox as high as 0.56 kg ai ha⁻¹ were required for more consistent control. A foliar application of imazamox at 0.14 kg ai ha⁻¹ killed the native eelgrass, whereas a rate of 0.84 kg ai ha⁻¹ had no effect on macroalgae. Damage to native eelgrass was minimized when the canopy was protected in the water column. An in-water exposure of < 90 µg ai L⁻¹ imazamox for 2 to 3 h had no observed effect on native eelgrass. Movement of imazamox off-site in the water column during the receding or flood tides after treatment was minimal, with a resulting dose and exposure time below what was required to markedly affect nontarget eelgrass.

Key words: Estuary, Willapa Bay, *Zostera japonica*, *Zostera marina*.

INTRODUCTION

Two seagrass congeners in the genus *Zostera* occur on the West Coast of North American estuaries, the native eelgrass (*Zostera marina* L.) and the nonnative Japanese eelgrass (*Zostera japonica* Asch. & Graebn.) (Ruesink et al. 2010, Shafer et al. 2014). The nonnative Japanese eelgrass sustains many of the ecosystem functions of the native eelgrass, including supporting diverse benthic assemblages, providing carbon to the estuarine food web, structural support for other primary producers, and habitat for juvenile salmonids and

other fish species (Bulthuis 2013, Shafer et al. 2014). Japanese eelgrass, however, also has noted negative effects (Bando 2006, Tsai et al. 2010, Fisher et al. 2011). In Willapa Bay, WA, it has infested thousands of hectares of commercial Manila clam beds, where it reduces annual clam growth by 15 to 25% and results in a cumulative total net loss of approximately U.S. \$47,407 ha⁻¹ for each harvest cycle of Manila clams (Patten 2014). Because of its economic impact, the Washington State Noxious Weed Control Board declared Japanese eelgrass a Class C noxious weed (WA State Noxious Weed Control Board 2012). The California Department of Fish and Game has declared an eradication effort for Japanese eelgrass in Humboldt Bay, CA (CA Dept. of Fish and Game 2009).

There are limited nonchemical management options for Japanese eelgrass (Schlosser 2007, WA Dept. of Ecology 2014). The herbicides glyphosate (Bulthuis and Shaw 1993, Patten 2003, Major et al. 2004) and imazapyr (Patten 2003) were partially effective on Japanese eelgrass, but only when the canopy was dry. Both of these chemistries lack tolerance for residue levels on food, however, and would not be suitable for use on commercial clam beds. Imazamox,¹ a recently registered, aquatic herbicide with a use pattern that includes estuarine and marine sites (EPA 2009), is exempt from all uses of food-residue tolerance requirements, including shellfish (WA Dept. of Ecology 2014). Because of its suitability for potential use, imazamox was assessed for the management of Japanese eelgrass across a range of tidal estuary conditions. In addition, studies were conducted to assess nontarget impacts to native eelgrass and macroalgae and to develop environmental concentration data for use in risk assessments under estuarine conditions.

MATERIALS AND METHODS

Study location

Research was conducted on the tidflats of Willapa Bay, WA, at a tidal height zone of 0.75 to 1.5 m between the years 2006 and 2013. Willapa Bay is a large, shallow bar-built estuary with 347 km² in surface area at mean higher high water (MHHW) and 191 km² at mean lower low water (MLLW). The tidal range between MHHW and MLLW is 2.4 to 3.4 m. More than half of the estuary's surface area and volume is drained at low tide (Hickey and Banas 2003). Approximately 20% of the intertidal area is used for commercial aquaculture of Pacific oysters (*Crassostrea gigas*

*Professor, Washington State University Long Beach Research and Extension Unit, 2907 Pioneer Rd, Long Beach, WA 98631. Corresponding author's E-mail: pattenk@wsu.edu. Received for publication March 26, 2014 and in revised form May 29, 2014.

TABLE 1. EXPERIMENTAL CONDITIONS FOR JAPANESE EELGRASS EFFICACY AND NONTARGET IMPACT STUDIES.

Site	Date of Application	Plot Size (m)	No. of Replications	Vegetation Type	Amount of Water Covering Plant Canopy	Time Before Tidal Coverage (h)
1	20 September 2006	4 × 7	3	Japanese eelgrass	Thin layer of water	3.5
2	15 April 2007	3 × 11	3	Japanese eelgrass	Canopy moist; no water cover	4.0
3	3 March 2007	4 × 7	3	Japanese eelgrass	Thin layer of water	3.5
4	27 April 2009	4 × 7	3	Japanese eelgrass	Canopy dry	3.5
5	10 June 2009	2 × 4	3	Japanese eelgrass	Canopy dry	3.5
6	1 January 2007	3 × 7	3	Mixed Japanese eelgrass and native eelgrass	Dry to submerged	2.5
7	28 May 2008	3 × 4	4	Mixed Japanese eelgrass and macroalgae	Canopies dry	2.5
8	7 June 2011	2 × 2	15	Mixed Japanese eelgrass and native eelgrass	0.5–1 cm	2.5
9	7 July 2011	5 × 6	12	Mixed Japanese eelgrass and native eelgrass	Canopies moist, no water cover	2
10	17 June 2013	2 × 2	4	Japanese eelgrass seedlings	Dry	2
11	17 June 2013	2 × 2	4	Japanese eelgrass seedlings	Dry	3
12	17 June 2013	2 × 2	4	Japanese eelgrass seedlings	Dry	1
13	27 May 2010	33 × 33	4	Native eelgrass	0–15 cm	2.5
14	7 May 2012	30 × 70	1	Native eelgrass	0–30 cm	3
15	23 May 2013	9 × 33	1	Japanese eelgrass	Dry	1.5

Thunberg) and Manila clams (*Ruditapes philippinarum* Adams and Reeve) (Feldman et al. 2000).

Trials for efficacy rate and nontarget impacts

Established stands of pure Japanese eelgrass, mixed Japanese eelgrass and native eelgrass, or mixed species of macroalgae were directly oversprayed with imazamox in a series of replicated experiments, using a randomized complete-block design, between the spring and late summer of 2006 and 2013. Depending on the experiment, treatments were applied with a carbon dioxide (CO₂)-powered or hand-powered backpack sprayer, using a boom with varying length equipped with TeeJet 11025 spray nozzles.² Imazamox rates ranged from 0.022 to 0.84 kg ai ha⁻¹, with or without the surfactant Competitor,³ at 2.8 l ha⁻¹. Estuarine water was used as the carrier, and the spray volume was 230 L ha⁻¹. Treatments were applied to Japanese eelgrass once the tidal water had completely drained off the site. For sites with native eelgrass, treatments were made after water had receded off the site, but when there was still a thin (approximately 0.25 to 0.5 cm) layer of water over the top of the canopy. Sites with macroalgae were dry, with no protective water film over the algae. The three algae species present—*Ulva intestinalis* L., *Ulva flexuosa* Wulfen, and *Polysiphonia hendryi* var. *deliquescens* Hollenberg—were affixed in approximately equal amounts to surface gravel at the site. Plot size, replication number, site conditions, and dry time before tidal coverage for each trial are detailed in Table 1 (Sites 1 to 12). Plots were evaluated for efficacy or for nontarget impacts at 1 to 9 mo after treatment (MAT) based on a visual rating of the percentage of cover, or the percentage of change in Japanese eelgrass seedling density or native eelgrass shoot length before and after treatment.

Additional nontarget assessments were made for native eelgrass on large sites treated with 0.14 kg ai ha⁻¹ imazamox. Sites contained both eelgrass species located on well-drained gently sloping ground, in shallow, isolated pools containing 5 to 15 cm of static water and in shallow tidal-drainage swales that started on-site and moved off-site with water draining off the treated area. At the first location, Site 13 (Table 1) native eelgrass shoot growth was measured in

the static pools at 0, 1, and 2 MAT as a function of the depth of water (0, 5, 10, and 15 cm). Plants were marked within each pool to allow for repeated measures of eelgrass shoot length. The mean number of shoots measured per plot was 25. There were four replicated pools per water depth. The calculated in-water exposure concentrations before tidal flooding for the 5, 10, and 15 cm depth pools were 278, 139, and 93 µg ai L⁻¹, respectively. At the second site (Site 14, Table 1) the percentage of reduction in native eelgrass coverage was measured at 21 d after treatment (DAT) in static pools (20 to 30 cm deep, $n = 4$) and in shallow drainage swales at the bottom edge of the treated zone (< 2 cm deep, $n = 7$; and 5 to 10 cm deep, $n = 10$).

Imazamox concentrations in water, sediment, and eelgrass

To assess water concentration of imazamox that could result from a typical treatment, water samples from Site 14 were obtained from a tidal pool, the tidal swale within the treated area, as it drained off the site during the ebb tide, and on the flood/shore side of the plot during the first and second flood tides after treatment. On-site samples were collected immediately after treatment. For the swale that drained the treated area, samples were collected 30 to 45 min after treatment in the middle of the swale at 0, 30, 60, and 120 m from the edge of the treated zone. Sample locations for the first flood tide after treatment were collected at five locations along transects that radiated out from the treatment zone (3 m inside the treatment zone, and 3, 30, 60, and 120 m outside the treatment zone). The transects were laid to run along the middle and outer two edges of the flood water as it moved over and beyond the treated zone. Samples along transects were collected as soon as the incoming flood water reached the 8-cm depth. All other samples were collected from the middle of the water column for that location. Water samples were collected in 60 ml Nalgene amber HDPE bottles.⁴ Samples were held on ice in a dark cooler and shipped to the laboratory within 24 h. Samples were analyzed by SePRO Lab Services⁵ using a Shimadzu LC-20⁶ high-performance liquid chromatography

TABLE 2. AVERAGE PERCENTAGE OF COVER OF ESTABLISHED JAPANESE EELGRASS AS A FUNCTION OF IMAZAMOX RATE WITH SURFACTANT.

Imazamox (kg ai ha ⁻¹)	Site 1	Site 2	Site 3
	Cover (%) ^{1,2}		
0	100 b	88 b	100 d
0.07	—	—	30 c
0.14	75 ab	10 a	16 bc
0.28	70 ab	7 a	9 ab
0.56	53 a	—	—

¹Sites 1, 2, and 3 were visually rated 9, 2, and 4 mo after treatment, respectively, for percentage of cover.

²Means within a column followed by same letter do not significantly differ (Waller-Duncan, $\alpha = 0.05$).

(HPLC), method ISO 17025,⁷ within 48 h of their collection. The limit of herbicide detection was 1 $\mu\text{g ai L}^{-1}$.

To assess imazamox concentrations in sediment and eelgrass, a sandy sediment location, Site 15 (Table 1), was treated with 0.14 kg ai ha⁻¹ imazamox. Samples were collected 24 h after treatment. Sediment samples, 0 to 5 cm deep, were obtained using a 7-cm coring device, from six locations across the site, and placed in sample bags. Eelgrass samples were collected from three locations at the site. Samples were triple rinsed in off-site estuarine water to remove any contaminated sediment and placed in sample bags. Sediment and eelgrass samples were immediately placed on ice in a dark cooler after collection, shipped on ice within 2 h, and chemically stabilized in the laboratory within 24 h. Samples were analyzed within 48 h of collection by Pacific Agricultural Laboratory,⁸ using U.S. Environmental Protection Agency–approved HPLC methods. The limits of detection were 0.5 and 100 $\mu\text{g ai L}^{-1}$ for sediment and vegetation, respectively.

Statistical analysis

Herbicide efficacy and nontarget plant data were analyzed by one-way ANOVA using SigmaPlot 12 software.⁹ For data with homogeneity of variance, mean separation was accomplished by Waller-Duncan *t* test ($\alpha = 0.05$). Nonparametric data was analyzed by Kruskal-Wallis one-way ANOVA on ranks, and mean separation were analyzed by protected Fisher's Protected LSD test ($\alpha = 0.05$).

RESULTS AND DISCUSSION

Efficacy

Imazamox controlled established Japanese eelgrass, with or without surfactant, across a range of rates, from 0.035 to 0.84 kg ai ha⁻¹ (Tables 2–4). A fall application was less effective than that in spring or early summer, even at very high rates (Table 2). At most sites, a rate of 0.14 kg ai ha⁻¹ was adequate for good control, but one site required 0.28 kg ai ha⁻¹ (Table 5), and another required 0.56 kg ai ha⁻¹ (Table 2). A layer of water over Japanese eelgrass at application decreased efficacy (Table 5). Seedlings were controlled with rates as low as 0.022 kg ai ha⁻¹ (Table 5).

These results indicate that control of established Japanese eelgrass or seedlings with imazamox under ideal tidal

TABLE 3. AVERAGE PERCENTAGE OF COVER OF ESTABLISHED JAPANESE EELGRASS AS A FUNCTION OF IMAZAMOX RATE WITHOUT SURFACTANT.

Imazamox (kg ai ha ⁻¹)	Site 4	Site 5
	Cover (%) ^{1,2}	
0	100 c	100 c
0.035	2 b	8 b
0.07	0 a	2 ab
0.105	0 a	0 a
0.14	0 a	0 a
0.21	0 a	0 a

¹Sites were visually rated 1 mo after treatment for percentage of cover.

²Means within a column followed by same letter do not significantly differ (Waller-Duncan, $\alpha = 0.05$).

conditions, when the canopy was completely exposed and dry during low tide, can be obtained with ≤ 0.035 kg ai ha⁻¹ imazamox without the need for a surfactant. Under tidal conditions less than ideal, where Japanese eelgrass still had a protective water layer over it, rates of imazamox as high as 0.56 kg ai ha⁻¹ imazamox were required for more consistent control.

Nontarget eelgrass and macroalgae effects

The effect of imazamox on native eelgrass was dependent on the conditions at the time of application. Imazamox applied over the top of a fully exposed canopy killed native eelgrass (Sites 6 and 9; Tables 4 and 5). Damage to native eelgrass from imazamox was reduced or minimized with an in-water exposure. This occurred when treatments were made at a site where there was a thin protective layer of slowly flowing water over native eelgrass canopy (Site 8, Table 4). In this situation, only the 0.28 kg ai ha⁻¹ rate had a significant effect on the canopy.

Native eelgrass located in well-drained sections of upper intertidal zones would likely have an exposed canopy during a typical low tide and be killed by an application of imazamox. The biological significance of native eelgrass removal in this tidal range is likely to be minor. Native eelgrass doesn't normally occur in this upper tidal range because it lacks tolerance to desiccation. Its existence in these zones is only due to that fact that Japanese eelgrass slows tidal drainage and facilitates the establishment of native eelgrass in higher, normally drier, tidal zones (Ruesink et al. 2010). Without Japanese eelgrass, these sites dewater enough during summer low tides to normally desiccate native eelgrass.

The greatest ecological risk to native eelgrass from imazamox is from short-term, unintentional in-water exposure at locations where it is naturally found. This could occur when the concentration and exposure time (CET) to imazamox in on-site static pools and swales and off-site drainage swales became high enough to cause damage. At Site 13, 1 MAT, after an overspray of static pools 5, 10, and 15 cm deep, corresponding to calculated doses of 280, 140, and 90 $\mu\text{g L}^{-1}$ for 2.5 h, respectively, native eelgrass had 50%, -21%, and 8% changes in mean shoot growth, respectively (Table 6). After 2 MAT, native eelgrass had begun to recover, and there was no statistical difference between water depths. At Site 14, an overspray of static

TABLE 4. AVERAGE PERCENTAGE OF CONTROL OF ESTABLISHED JAPANESE EELGRASS AND NONTARGET SPECIES AS A FUNCTION OF IMAZAMOX RATE WITH SURFACTANT.

Imazamox (kg ai ha ⁻¹)	Site 6		Site 7		Site 8		Site 9	
	Japanese Eelgrass	Native Eelgrass	Japanese Eelgrass	Macroalgae Cover (%) ^{1,2}	Japanese Eelgrass	Native Eelgrass	Japanese Eelgrass	Native Eelgrass
0	90 b	90 b	58 b	100	53 b	53 b	100 b	100 b
0.14	4 a	7 a	—	—	53 b	21 b	—	—
0.21	—	—	0 a	100	—	—	—	—
0.28	2 a	—	—	—	29 a	6 a	0 a	0 a
0.42	—	—	0 a	100	—	—	—	—
0.84	—	—	0 a	100	—	—	—	—

¹Site 6, 7, 8, and 9 were visually rated 3, 5, 2, and 3 mo after treatment, respectively, for percentage of change in cover.

²Means within a column followed by same letter do not significantly differ (Waller Duncan, $\alpha = 0.05$).

pools with 20 to 30 cm of standing water (100 to 200 mg ai L⁻¹ nominal concentration, 181 mg ai L⁻¹ measured concentration) resulted in no observed reduction in the percentage of native eelgrass cover after 3 h exposure. In shallow drainage swales, at the bottom edge of the treated zone, < 2 cm and 5 to 10 cm deep (541 mg ai L⁻¹ measured concentration), there was a mean \pm standard error (SE) 65% \pm 5% and 96% \pm 2% reductions, respectively, in the percentage of native eelgrass cover. Based on observed and nominal concentrations of imazamox in water, a CET for native eelgrass can be inferred from the above field data. For 2 to 3 h exposure, there is minimal damage at 90 μ g ai L⁻¹, suppressed growth at 140 to 280 μ g ai L⁻¹, and death at > 400 μ g ai L⁻¹ or from a direct canopy application.

Native eelgrass provides valuable ecological services and is a protected species (Shafer et al. 2104). Regulatory agencies have expressed concerns over nontarget impacts to native eelgrass that could occur from using an herbicide to control Japanese eelgrass (Bulthuis 2013, Shafer et al. 2014, WA Dept. Ecology 2014). Overall, these results indicate that the nontarget impact of imazamox to native eelgrass could occur if it was directly sprayed, or if water moving off treated areas concentrated imazamox to high enough levels to exceed the dose-exposure threshold. By treating early enough in the season to ensure minimal water on-site during treatments, by not directly spraying pools or drainage swales on-site, and by leaving a 10-m buffer around lower edges of treated sites, nontarget damage to native eelgrass is likely to be negligible. The National Pollutant Discharge Elimination System permit issued for this use contains these precautions and extends the 10-m buffer

TABLE 5. AVERAGE PERCENTAGE OF REDUCTION IN JAPANESE EELGRASS SEEDLING DENSITY AS A FUNCTION OF IMAZAMOX RATE WITHOUT SURFACTANT.

Imazamox (kg ai ha ⁻¹)	Site 10	Site 11	Site 12
	Reduction in seedling density (%) 1 mo after treatment ^{1,2}		
0	0 b	0 b	0 b
0.022	96 a	100 a	100 a
0.044	94 a	100 a	100 a
0.066	96 a	100 a	100 a
0.088	96 a	97 a	100 a

¹Percentage of change in seedlings per plot between 0 and 1 mo after treatment.

²Means within a column followed by same letter do not significantly differ (Waller-Duncan, $\alpha = 0.05$).

around the entire treated site (WA State Dept. of Ecology 2014).

Unlike native eelgrass, the risk to microalgae from a direct application of imazamox appears minimal (Table 4). There was no observed effect on *U. intestinalis*, *U. flexuosa*, or *P. hendryi* var. *deliquescens* at rates up to 6-fold beyond the recommended 0.14 kg ai ha⁻¹ rate. Similar studies on red algae (*Griffithsia pacifica* Kylin) and marine diatom (*Skeletonema costatum* (Greville) Cleve) (ENVIRON 2012) failed to generate an effect at the anticipated environmental exposure concentrations.

Imazamox concentrations in water, sediment, and eelgrass

Median water concentration in the first on-site flood water was 61 μ g ai L⁻¹. After the flood water left the site, the median concentrations at the 3-, 30-, 60-, and 120-m locations were 44, 7, 0, and 0 μ g ai L⁻¹, respectively (Table 7). The imazamox concentration in water in the second flood tide to cover the site was 6.0 μ g ai L⁻¹. Water sampled within the treated zone from two shallow pools had posttreatment imazamox concentrations of 181 and 541 μ g ai L⁻¹. Water moving off the site in a drainage swale had imazamox concentrations of 32, 7.6 and < 1 μ g ai L⁻¹ at 30, 60, and 120 m. Means \pm SE imazamox concentrations in sediment and Japanese eelgrass, 24 h after treatment, following two tidal flushes, were 5.9 \pm 2.14 μ g ai L⁻¹ and 1,016 \pm 256 μ g ai L⁻¹, respectively.

These data were used to determine the environmental exposure in vegetation, sediment, and water for the risk

TABLE 6. PERCENTAGE OF INCREASE IN SHOOT GROWTH OF NATIVE EELGRASS IN TIDE POOLS, 1 AND 2 MONTHS AFTER TREATMENT, WITH IMAZAMOX AS A FUNCTION OF POOL WATER DEPTH.

Depth of water (cm)	Months after Treatment	
	1	2
	% increase in mean shoot length ^{1,2}	
0	Dead a	Dead a
5	-50 bc	20 b
10	-21 cd	24 b
15	8 d	41 b

¹Repeated measures of the same shoots 0, 1, and 2 mo after treatment.

²Treatment difference was analyzed by Kruskal-Wallis one-way ANOVA on ranks, and means within a column followed by same letter do not significantly differ according to Fisher's Protected LSD test ($\alpha = 0.05$).

TABLE 7. IMAZAMOX CONCENTRATION IN THE LEADING EDGE OF THE INCOMING TIDAL WATER FOLLOWING A TREATMENT OF A 30- BY 70-METER JAPANESE EELGRASS SITE ON SANDY SEDIMENT, SITE 14.

Sample Locations	Imazamox ($\mu\text{g ai L}^{-1}$)		
	Maximum	Minimum	Median
3 m inside plot upper edge	82	24	61
3 m outside plot upper edge	79	35	44
30 m outside plot upper edge	83	5	7
60 m outside plot upper edge	18	< 1	0
120 m outside plot upper edge	6	0	0

assessment on imazamox during estuarine use (ENVIRON 2012). For consumption of treated eelgrass, the hazard quotient for acute-ingestion exposure, subchronic ingestion dose, and chronic subacute-ingestion dose for three indicator species: mallard (*Anas platyrhynchos* L.), rainbow trout (*Oncorhynchus mykiss* Walbaum), and Dungeness crab (*Metacarcinus magister* Dana), ranged from 0.0001 to 0.003 (ENVIRON 2012). These are several orders of magnitude below what would be considered a hazard. Nevertheless, hunters have expressed concern that certain waterfowl species, like wigeon (*Anas americana* Gmelin), which forage on Japanese eelgrass, could be affected by consuming eelgrass treated with imazamox. The approximately 1 mg ai L^{-1} of imazamox found in Japanese eelgrass 24 h after treatment is three orders of magnitude less than the 1,950 mg ai L^{-1} avian LD_{50} (ENVIRON 2012). In addition, the imazamox residue would be very short-lived. The shoots rapidly degrade posttreatment and, like other aquatic plants, the desorption rate is rapid. Vassios (2010), for example, found that 46% of imazamox was rapidly desorbed in Sago pondweed [*Stuckenia pectinata* (L.) Börner] in the first 12 h after treated plants were transferred to water with no herbicides.

A review of the potential risks of imazamox suggests that nontarget aquatic macrophytes could be at risk if imazamox concentrations were to build up in aquatic sediments (New York State Dept. of Environ. Conserv. 2003). These results suggest that concerns about high sediment concentration are not warranted. Because of the high solubility of imazamox in water ($> 4000 \text{ mg ai L}^{-1}$), rapid tidal flushing and low binding affinity for sediment (K_{oc} [binding coefficient] = 5.3), the level of sediment imazamox found ($5 \mu\text{g kg}^{-1}$) is likely to drop below the detection limits ($0.5 \mu\text{g kg}^{-1}$) within a short period. Overall, the levels of imazamox found in water, sediment, and vegetation in this study were several orders of magnitude lower than the LC_{50} toxicity of imazamox for the most sensitive aquatic organisms ($> 100 \text{ mg ai L}^{-1}$) (EPA 2009, ENVIRON 2012, WA Dept. Ecology 2014). Based on these results, the short exposure to the imazamox concentration found in this study is unlikely to present a risk to the aquatic ecosystem.

Conclusions for integrated control

These trials indicate imazamox is an efficacious treatment for invasive eelgrass and, when applied under the right conditions, it is not likely to result in nontarget impacts to estuarine species of concern. The lowest effective doses of

imazamox to manage established plants and seedlings are 0.14 and 0.04 kg ai ha^{-1} , respectively. Application too early in the spring would miss controlling newly germinating Japanese eelgrass seedlings, which peak in mid March and tail off into early June (Ruesink et al. 2010). Application later in the season is problematic because of the rapidly growing Japanese eelgrass canopy slowing or preventing tidal dewatering during low tides and ultimately leaving the canopy with a protective water layer. Dense mats of Japanese eelgrass reduce water flow by up to 40% compared with nonvegetated mudflats (Tsai et al. 2010). In addition, application of imazamox to a site that doesn't fully dewater increases the potential of nontarget impact to native eelgrass. In these situations, imazamox more easily drains off-site, thus concentrating in the swales containing native eelgrass. The ideal spray window would be from late April to early June, after most seed germination occurs, but while the tidal flats are still dewatered during low tides. Since these sites are mostly dry during a low tide, applications of imazamox to control Japanese eelgrass during this period would help minimize the risk for nontarget impacts to native eelgrass. Risk to native eelgrass can also be minimized by avoiding spraying near or over pools or near drainage swales containing native eelgrass.

SOURCES OF MATERIALS

- ¹TeeJet technologies, P.O. Box 7900, Wheaton, IL 60187-7901.
- ²Imazamox (Clearcast), SePRO Corporation, 11550 N. Meridian St., Suite 600, Carmel, IN 46032.
- ³Competitor, Wilbur-Ellis Co., P.O. Box 16458, Fresno, CA 93755.
- ⁴Amber HDPE bottles, Nalge Nunc International Corporation, 75 Panorama Creek, Dr., Rochester, NY 14625.
- ⁵SePRO Lab Services, 16013 Watson Seed Farm Rd., Whitakers, NC 27891-9114.
- ⁶LC-20 HPLC systems, Shimadzu Scientific Instruments, 7102 Riverwood Dr., Columbia, MD 21046.
- ⁷ISO 17025 Standard: General requirements for the competence of testing and calibration laboratories, International Organization for Standardization, ISO Central Secretariat, Chemin de Blandonnet 8, CP 401, 1214 Vernier, Geneva, Switzerland.
- ⁸Pacific Agricultural Laboratory, 12505 NW Cornell Rd., #4, Portland, OR 97229.
- ⁹SYSTAT Software, Inc., 1735 Technology Dr., Suite 430, San Jose, CA 95110.

ACKNOWLEDGEMENTS

Funding for this research was provided by the Washington State Commission for Pesticide Registration and Washington Department of Fish and Wildlife Oyster Reserve Fund. The author would like to thank Nick Haldeman, Chase Metzger, and Scott Norelius for their technical assistance.

LITERATURE CITED

- Bando KJ. 2006. The roles of competition and disturbance in a marine invasion. *Biol Invasions* 8:755-763.
- Bulthuis DA. 2013. Padilla Bay National Estuarine Research Reserve Technical Report No. 36, Science Presentation Abstracts from the workshop on The Science and Management of *Zostera japonica* in Washington: A meeting for state agencies. Padilla Bay National

- Estuarine Research Reserve. www.ecy.wa.gov/programs/sea/aquaculture/pdf/scienceAbstracts.pdf? Accessed April 14, 2015.
- Bulthuis DA, Shaw TC. 1993. Effects of application of glyphosate on the eelgrasses *Zostera marina* and *Zostera japonica* in Padilla Bay, Washington. Padilla Bay National Estuarine Research Reserve Technical Report No. 8. 45pp. <http://www.padillabay.gov/pdfs/Tech08.pdf> Accessed April 14, 2015.
- CA Dept. of Fish and Game. 2009. Stop the spread of dwarf eelgrass. http://www.csgc.ucsd.edu/BOOKSTORE/Resources/COMP__PUBS/web__eelgrass.pdf Accessed April 14, 2015.
- ENVIRON International Corporation. 2012. Screening-Level Ecological Risk Assessment of the Proposed Use of the Herbicide Imazamox to Control Invasive Japanese Eelgrass (*Zostera japonica*) in Willapa Bay, Washington State. <http://www.ecy.wa.gov/programs/wq/pesticides/enviroReview/riskAssess/riskassessmentimazamox110712.pdf>. Accessed April 14, 2015.
- [EPA] U.S. Environmental Protection Agency. 2009. Pesticide Product Label System (PPLS). Web site: <http://oaspub.epa.gov/pestlabl/ppls.home>. Accessed September 15, 2009.
- Feldman KL, Armstrong DA, Dumbauld BR, DeWitt TH, Doty DC. 2000. Oysters, crabs, and burrowing shrimp: review of an environmental conflict over aquatic resources and pesticide use in Washington State's (USA) coastal estuaries. *Estuaries* 23:141–176.
- Fisher JP, Bradley T, Patten KD. 2011. Invasion of Japanese eelgrass, *Zostera japonica* in the Pacific Northwest: A preliminary analysis of recognized impacts, ecological functions, and risks. http://www.nwcb.wa.gov/siteFiles/Japonica__White__Paper.pdf Accessed April 14, 2015.
- Hickey BM, Banas NS. 2003. Oceanography of the U.S. Pacific Northwest coastal ocean and estuaries with application to coastal ecology. *Estuaries* 26:1010–1031.
- Major WW, III, Grue CE, Grassley JM, Conquest LL. 2004. Non-target impacts to eelgrass from treatments to control *Spartina* in Willapa Bay, Washington. *J. Aquat. Plant Manage.* 42:11–17.
- New York State Dept. of Environ. Conserv. 2003. Imazamox—Active Ingredient Registration 3/03. http://pmep.cce.cornell.edu/profiles/herb-growthreg/fatty-alcohol-monuron/imazamox/clrcastr__mcl__0209.pdf Accessed April 14, 2015.
- Patten, K. 2014. The Impacts of Nonnative Japanese Eelgrass (*Zostera japonica*) on Commercial Shellfish Production in Willapa Bay, WA. *Agric. Sci.* 5:625–633.
- Ruesink JL, Hong JS, Wisheart L, Hacker SD, Dumbauld BR, Hessing-Lewis M, Trimble, AC. 2010. Congener comparison of native (*Zostera marina*) and introduced (*Z. japonica*) eelgrass at multiple scales within a Pacific Northwest estuary. *Biol. Invasions* 12:1773–1789.
- Schlosser S. 2007. National Fish and Wildlife Foundation Report: Humboldt Bay Cooperative Eelgrass Project. UC San Diego, CA: California Sea Grant College Program. Retrieved from: <http://escholarship.org/uc/item/9g98z1z1>. Accessed April 14, 2015.
- Shafer DJ, Kaldy JE, Gaeckle JL. 2014. Science and management of the introduced seagrass *Zostera japonica* in North America. *Environ. Manage.* 53:147–162.
- Tsai C, Yang S, Trimble AC, Ruesink JL. 2010. Interactions between two introduced species: *Zostera japonica* (dwarf eelgrass) facilitates itself and reduces condition of *Ruditapes philippinarum* (Manila clam) on intertidal flats. *Mar. Biol. (Berl.)* 157:1929–1936.
- Vassios JD. 2010. Evaluation of Herbicides for Control of Eurasian Water Milfoil and Sago Pondweed. MS thesis. Ft. Collins, CO: Colorado State University. digitool.library.colostate.edu/webclient/DeliveryManager?pid=82815. Accessed April 14, 2015.
- WA State Dept. of Ecology. 2014. General Permit and Environmental Impact Statement: Management of *Zostera japonica* on Commercial Clam Beds in Willapa Bay, Washington. <http://www.ecy.wa.gov/programs/wq/pesticides/eelgrass.html>. Accessed April 14, 2015.
- WA State Noxious Weed Control Board. 2012. Japanese Eelgrass. <http://www.nwcb.wa.gov/detail.asp?weed=173>. Accessed April 14, 2015.