Supplemental Information: WGHOGA NPDES and Sediment Impact Zone Applications

This serves as a response to Ecology's request (letter from Rich Doenges dated April 15, 2016) for additional information regarding WGHOGA's NPDES (National Pollutant Discharge Elimination System) permit and Sediment Impact Zone (SIZ) applications for the use of imidacloprid to control burrowing shrimp infestations in Grays Harbor and Willapa Bay. The information requests in the letter and appended memoranda from Barry Rogowski of the Toxics Cleanup Program have been discussed with Ecology staff, and WGHOGA's detailed responses are outlined below.

1. Ecology's Request to include a "general description of the discharger's proposed sediment monitoring and reporting":

WGHOGA agrees with Ecology that the draft NPDES Permit from 2014 provides a good framework for designing an appropriate monitoring program for the proposed use of imidacloprid that is the subject of this current application. As WGHOGA representatives have discussed with Ecology, the monitoring program needs to be tailored to the changes in the proposed use of imidacloprid that is the subject of the current NPDES and SIZ applications. The reduction in total acreage proposed to be treated (from 2,000 annual acres to 500) and the elimination of aerial spraying both result in smaller plot sizes that will be the subject of individual treatments.

At the time that Ecology wrote its letter to WGHOGA (April 15) the Department's thinking appears to have been that a revised permit application should include a complete proposal for monitoring. Subsequent to the letter, WGHOGA representatives have had early, but productive discussions with Ecology staff on monitoring requirements for the new permit. These discussions have helped identify monitoring as a significant component of any new NPDES permit, and something that will most probably require multiple technical discussions between WGHOGA representatives and Ecology staff. Thus, rather than propose a draft monitoring plan here, WGHOGA requests that Ecology and WGHOGA representatives continue the technical discussions needed to work out a justifiable and feasible monitoring program that will be incorporated in the new NPDES permit and SIZs.

2. Ecology's request for more information on locations where imidacloprid will be applied in Southern Willapa Bay, potentially including a map showing parcels, GPS coordinates, and the landowners of property proposed for use as, or potentially affected by the SIZ.

Attached are maps for parcel locations where imidacloprid may be applied in Willapa Bay (Exhibit A) and Grays Harbor (Exhibit B). Although Ecology's request was limited to Southern Willapa Bay, WGHOGA believes a more comprehensive set of maps would bolster our NPDES and SIZ applications, and ultimately provide useful information for the Department and public. In addition, attached in table format is bed information for Willapa Bay and Grays Harbor plots that would be included into the NPDES permit. WGHOGA has endeavored to provide accurate locations for all plots, and for all growers within our group. In producing the maps we have found some minor inaccuracies in Pacific County parcel designations, which we have corrected. And we have also had incomplete information from a few, smaller growers. Thus, although the current maps represent the current, best available information, WGHOGA reserves the right to modify this map in the future should we become aware of new or improved information. We would give prompt notice to Ecology, and provide them with a modified map(s) should that event occur.

As detailed in the SIZ application, the annual maximum acreage that would be treated in Willapa Bay each year is 485 acres. WGHOGA will decide each year where in Willapa Bay those 485 acres are located. WGHOGA needs some flexibility in how those acres are allocated, but can still commit to maximum levels of treatment, within a given year, of 125 acres, 485 acres, and 30 acres of the North, Central, and Southern portions of the bay, respectively (see Exhibit A for delineation of these zones). Our Exhibit A includes circles, drawn to scale, that identify the area encompassed by these acreage limits. Combining all three areas, WGHOGA is proposing to spray no more than 0.7 percent of the Willapa Bay estuary, annually.

For Grays Harbor the annual maximum acreage that would be treated is 15 acres, or 0.02 percent of the estuary. Our Exhibit B includes a scaled circle representing an area of this size.

3. Ecology's request to withdraw the statement regarding the extensive research done by WGHOGA, WSU, UW, and PSI over the past eight years.

WGHOGA understands, from conversations with Ecology, that the concern is that the state of the science regarding imidacloprid application to Willapa Bay and Grays Harbor is less certain than this statement indicates, particularly with respect to use of this chemical in sediments with higher levels of organic carbon. WGHOGA agrees that this statement from its application can be removed or ignored. We anticipate additional technical discussions with Ecology staff on imidacloprid's effects generally, and specifically in areas with higher organic carbon sediments.

4. Identification of locational considerations:

A. Public Shellfish Beds. WGHOGA has attached maps of Willapa Bay (Exhibit C) and Grays Harbor (Exhibit D) showing all public shellfish beds, as listed and identified by the Washington Department of Fish and Wildlife (WDFW, http://wdfw.wa.gov/fishing/shellfish/beaches/). WDFW information identifies three public areas in or near Grays Harbor, and an additional five in or near Willapa Bay. For Grays Harbor, two of the sites are coastal beaches outside the estuary, which are listed for razor clams, and one at the mouth is listed for Dungeness crab (Attachment D). Of the five areas in Willapa Bay, four, all within the estuary, are listed for clams and oysters, while the fifth is the coastal beach area listed for razor clams (Attachment C).

   WGHOGA used GIS to measure the distances from each of these public shellfishing beds to the nearest plot proposed for inclusion in the NPDES and SIZ applications. All distances were measured in the water given that imidacloprid movement off the plots would be via water movements. Those distances are as follows:

Grays Harbor

- Twin Harbors: 3.15 miles
- Westport Boat basin: 1.91 miles
- Copalis: 5.19 miles

Willapa Bay

- Long Beach: 5.7 miles
- Nahcotta: 0.16 miles
- Long Island Pinnacle Rock: 0.14 miles
- Long Island NW: 0.07 miles
- Nemah: 1.17 miles
- Hawks Point: 0.21 miles

Public areas for razor clam harvest outside Grays Harbor (Copalis, Twin Harbors) and Willapa Bay (Long Beach) are unlikely to be exposed to any but the most dilute concentrations of imidacloprid given their distance from treatment plots and their full exposure to the larger body of coastal waters. The other public shellfishing areas range from 1.9 miles to 0.07 miles (approx. 400 feet) from proposed treatment plots. As with past permits for application of carbaryl and imidacloprid, WGHOGA expects the new NPDES permit to include public notification procedures to advise potential users of these areas of the planned location and timing of imidacloprid treatments.

B. <u>Identification of recreationally and commercially important species</u>. Information regarding commercially or recreationally important species is provided in the SIZ Application section titled "Public Recreation Areas," and in the section titled "Spawning Areas, Nursery Areas, and Areas Used by Species of Economic Importance." In addition, a detailed evaluation of these species was included in Section 3 of the Environmental Impact Statement for the prior permit, incorporated here by reference.

These discussions indicate that Dungeness crab, various salmonid fish species, green sturgeon, and flatfish, including Pacific halibut, occur in Willapa Bay and Grays Harbor, and could occur in areas that would be treated under this permit. Because the areas to be treated are exposed at low tide, and because they are privately owned, WGHOGA believes that minimal recreational use of the shellfish beds that would be included in the draft permit would occur. In addition, even where species, like Dungeness crab, regularly occur on the subject beds, they are typically juveniles that are not the subject of any recreational or commercial fishery. To the extent Dungeness crab harvest occurs in Willapa Bay or Grays Harbor, it occurs in deeper channels and near boat launches, separated by significant distances from areas proposed to be treated. Dungeness crab do not generally occur on barren mud or sand like those found in shrimp-impacted areas.

C. Public Recreation Areas: In addition to the public recreation areas identified in the SIZ Application (Willapa National Wildlife Refuge, the Willapa Bay Trail, the Willapa River, and the dike and saltmarsh areas adjacent to Ledbetter Point), WGHOGA acknowledges the existence of other recreation areas like the ones identified by Ecology. It is difficult to obtain a comprehensive map of all public recreation areas given the many jurisdictions and types of access. WGHOGA has prepared maps that show the location of state and county parks and reserves, and the boundaries of federal wildlife refuges in Willapa Bay (Exhibit E), and Grays Harbor (Exhibit F). WGHOGA welcomes input from Ecology, or during the public comment period for a draft permit, in order to update this map.

D. Waterfowl: Identifying which species of waterfowl and shorebirds (here referred to collectively as birds) in Willapa Bay and Grays Harbor that occur on oyster beds, and therefore could potentially be exposed to imidacloprid, is difficult to predict with any precision. A large number of species of birds may be found on oyster beds at least occasionally, but limited, intermittent use is unlikely to result in significant imidacloprid exposure (i.e., low probability of occurrence combined with low probability that any particular plot will have recently been sprayed). Further, bird use of these estuaries is overwhelmingly seasonal, with most species that overwinter having moved north before the first dates proposed for spraying under WGHOGA's permits. Obviously such birds, even if they occur on oyster beds, would have no risk of imidacloprid exposure. Similarly, birds that eat fish would only be present in the oyster beds during higher tides, when imidacloprid concentrations in water would be dilute. These bird species, and the list is extensive (e.g., loons, cormorants, herons, auks), would probably only be exposed to imidacloprid if they were to eat fish that, in turn, had eaten invertebrates containing imidacloprid. This is an unlikely exposure scenario, and one almost certainly unlikely to result in imidacloprid intake to levels that cause toxicity in birds.

Thus, of the bird species that are found in oyster beds, the group most likely to be exposed to imidacloprid are those that feed on invertebrates on those beds, and are present during the spring-summer months. Such birds are likely to forage largely or exclusively at low tide, when imidacloprid levels on just sprayed beds would be high. This could lead to dermal exposure. And consumption of invertebrates from treated plots could lead to exposure via ingestion pathways. Birds that eat invertebrates from oyster beds fall into four groups: plovers, shorebirds, gulls, and corvids (i.e., American or "common" crow).

A second group of bird species that could be exposed to imidacloprid are waterfowl that eat eelgrass and other vegetation. Although past trials with imidacloprid, conducted under Ecology SAPs, have rarely documented uptake of imidacloprid by eelgrass, some samples have tested positive. And waterfowl could also ingest imidacloprid from sediments or water they take in as they consume vegetation. This group of birds includes a number of species of dabbling ducks (e.g., mallards, widgeon) and geese.

The attached Exhibit G is the list of bird species found in Willapa Bay that was appended to the EIS. WGHOGA believes it to be a good indicator of bird species in Grays Harbor as well. Species in this list that have been highlighted in green meet one of two criteria: 1) they have been observed on oyster beds by the growers, or 2) they are listed as being commonly found in the bay for at least part of the year, and therefore can be assumed to occur on oyster beds. We did not screen this list to exclude species that are rare or not present on the estuaries during the spring-summer months, so our designations of species are conservative. This list excludes species that are rarely observed on the oyster beds and/or the bay. And it excludes bird groups that would not feed in and around the oyster beds (e.g., owls, passerines). Based on the discussion above, WGHOGA would assume that highlighted species of plovers, shorebirds, gulls and American crow are the most likely to be at risk from treatment of oyster beds with imidacloprid. Highlighted waterfowl species that eat vegetation, either as a primary food source (brant) or incidentally (dabbling ducks), and waterfowl that eat invertebrates (e.g., scoters) would also be at higher risk of exposure to imidacloprid.

However, there are a variety of reasons to conclude that no bird species is likely to suffer adverse effects from imidacloprid treatments. Extensive analysis of potential impacts to birds is presented in the EIS, and is incorporated by reference here. In addition, the attached Exhibit H provides an extensive review of potential imidacloprid toxicity to birds. In evaluating potential effects of imidacloprid on toxicity to birds, a key consideration is that this chemical has very low toxicity to birds, or, put another way, a very great deal of imidacloprid is required to produce sub-lethal or lethal impacts in birds. The application rate proposed by WGHOGA (0.5 lbs a.i./acre) has been shown in repeated field studies to produce water and sediment concentrations that are 1-3 orders of magnitude lower than levels observed to produce toxicity in birds. Hence, WGHOGA continues to believe the EIS's conclusion that direct toxicity to birds from application of imidacloprid is extremely unlikely.

Exhibit H also expands upon an idea presented in the EIS that imidacloprid applications, by reducing competition from burrowing shrimp, can increase the diversity of invertebrate prey available to shorebirds, producing a net benefit overall. Key to this analysis is that most shorebirds have short bills, and are therefore dependent on invertebrates species found in or near the sediment surface. These taxa of invertebrates are often reduced or eliminated when shrimp are at high densities.

WGHOGA anticipates additional technical discussions with Ecology staff on the potential impacts and benefits of imidacloprid use on birds.

5. Efficacy: AT WGHOGA's request, Dr. Kim Patten wrote a summary of efficacy studies and results from field trials and laboratory experiments over the past 10 years (Exhibit I). His key

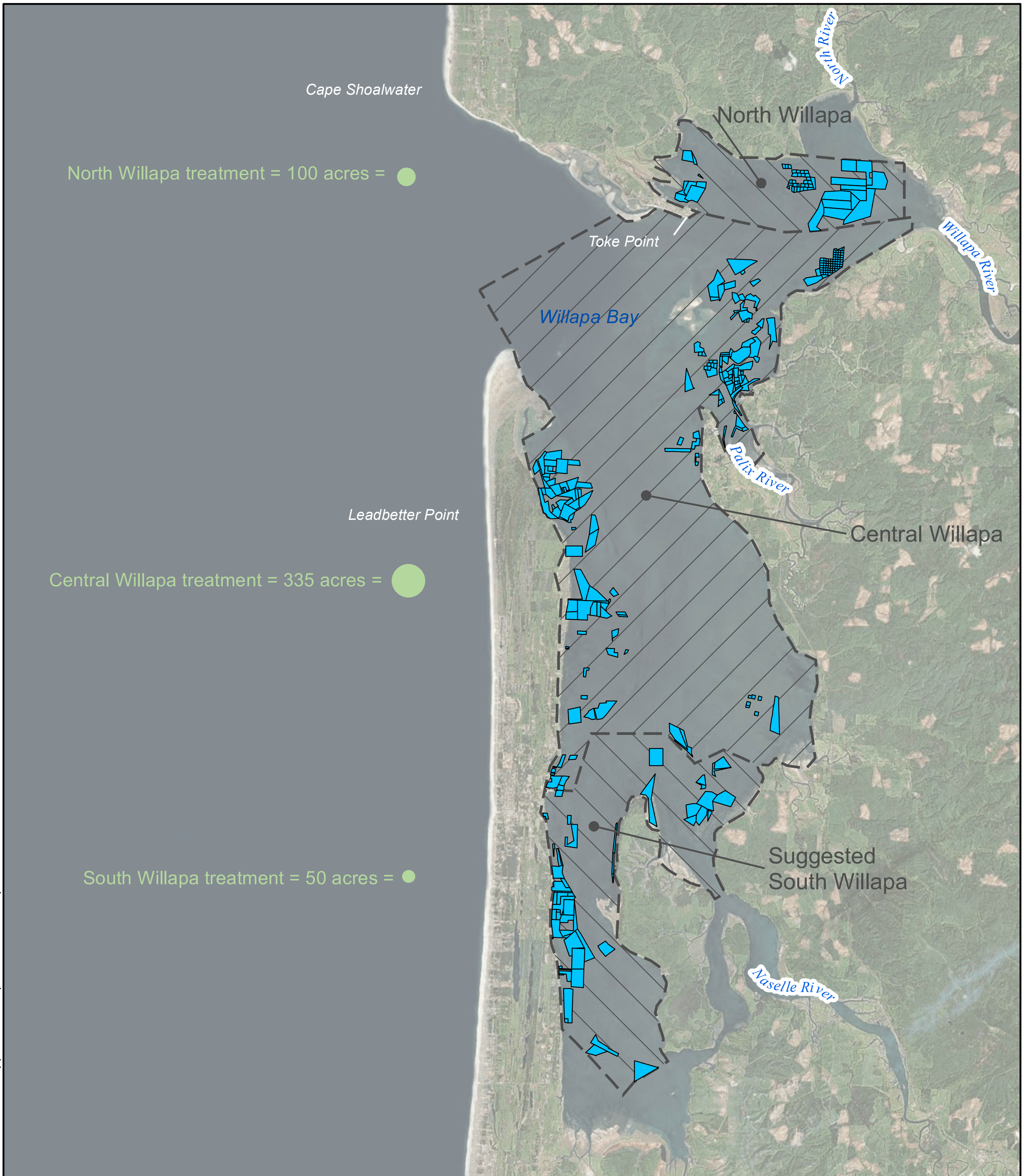
finding is that in the absence of either flowing water or heavy growth of eelgrass, efficacy of imidacloprid in reducing burrowing shrimp densities is consistently greater than 40%, and averages as much as 80% or more. Where flowing water or heavy eelgrass are present, efficacy can decline below 40% unless site-specific approaches to ensure chemical contact with the sediment-water interface can be enhanced. He recognizes that additional investigative work to optimize efficacy will have to be done in the future given there is no currently permitted way to conduct such trials. But based on his experience he suggests that use of pelletized forms of imidacloprid, reduction in eelgrass densities before treatment, and spot treatments may be effective.

6. Granular/pellet form: See the response to item 5, and Exhibit I. Dr. Patten's analysis of efficacy includes a variety of studies using the pelletized version of imidacloprid. He found a wide range in efficacy ranging from 40-80 percent under "normal" conditions (see values for formulation 0.5G in Table 1 of Exhibit I) to 30-70 percent under "moderate to thick densities of eelgrass" (Table 2 of Exhibit I). These are generally high levels of efficacy, and help explain why WGHOGA, in the current permit application, expects to use more pelletized versions of imidacloprid. Dr. Patten also offers the opinion that pelletized versions may be more effective in difficult treatment conditions than liquid applications.

7. Subsurface injectors: Dr. Patten's memo on efficacy includes data from tests using subsurface injectors to control burrowing shrimp (Exhibit I). These tests generally did not find that subsurface injectors provided superior efficacy over other application techniques. They did however, require additional time and equipment to use, and in practice would also require regular maintenance and replacement if used commercially in the future. Accordingly, WGHOGA is not requesting the NPDES and SIZ applications provide for commercial use of subsurface injectors. However, as part of its efforts to improve the efficacy of imidacloprid application via adaptive management, WGHOGA is requesting that the applications permit small scale, experimental use of subsurface injectors.

8. Although not included as an item in Ecology's April 15 letter, we know from our recent technical discussions with Ecology that there is interest in non-chemical approaches to burrowing shrimp control, perhaps as part of a commitment to integrated pest management (IPM) techniques in WGHOGA's permit. Ecology has specifically noted that a summary of past efforts with non-chemical controls would be helpful. Accordingly, WGHOGA asked Dr. Kim Patten of WSU to compile a summary of past experimental work on non-chemical controls (Exhibit J). His review documents the very wide variety of approaches that have been tried, and the varying levels of success. Of the methods tried, most failed to reduce burrowing shrimp densities. A few methods, like hand spraying individual burrows, did reduce shrimp densities, but required slow, expensive treatments that would not be viable at the scale of commercial shellfish beds. A few others (e.g., physical compression of sediments, high volume water injections) also reduced densities, but in the process appear to have severely reduced or eliminated non-target species of invertebrates as well, likely creating more impacts at the ecosystem level than chemical controls would.

In his conclusion, Dr. Patten states that no non-chemical approach is viable as a stand-alone treatment for burrowing shrimp due to logistics, cost, low efficacy, and/or impacts to non-target species. WGHOGA anticipates technical discussions with Ecology to evaluate whether and which non-chemical controls should be included as part of an IPM strategy approach to controlling burrowing shrimp. Within such an IPM approach, non-chemical methods might be proposed as stand-alone controls in particular locations or conditions, or as adjuncts to imidacloprid applications designed to improve the overall effectiveness of burrowing shrimp control.



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ESRI Basemap

Willapa Grays Harbor Oyster Growers Assoc.
Willapa Bay, Pacific County, Washington

Oyster Beds in Willapa Bay

12733-02 8/18/2016

HARTCROWSER

Exhibit

A

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ESRI Basemap

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Willapa Grays Harbor Oyster Growers Assoc.
Grays Harbor County, Washington

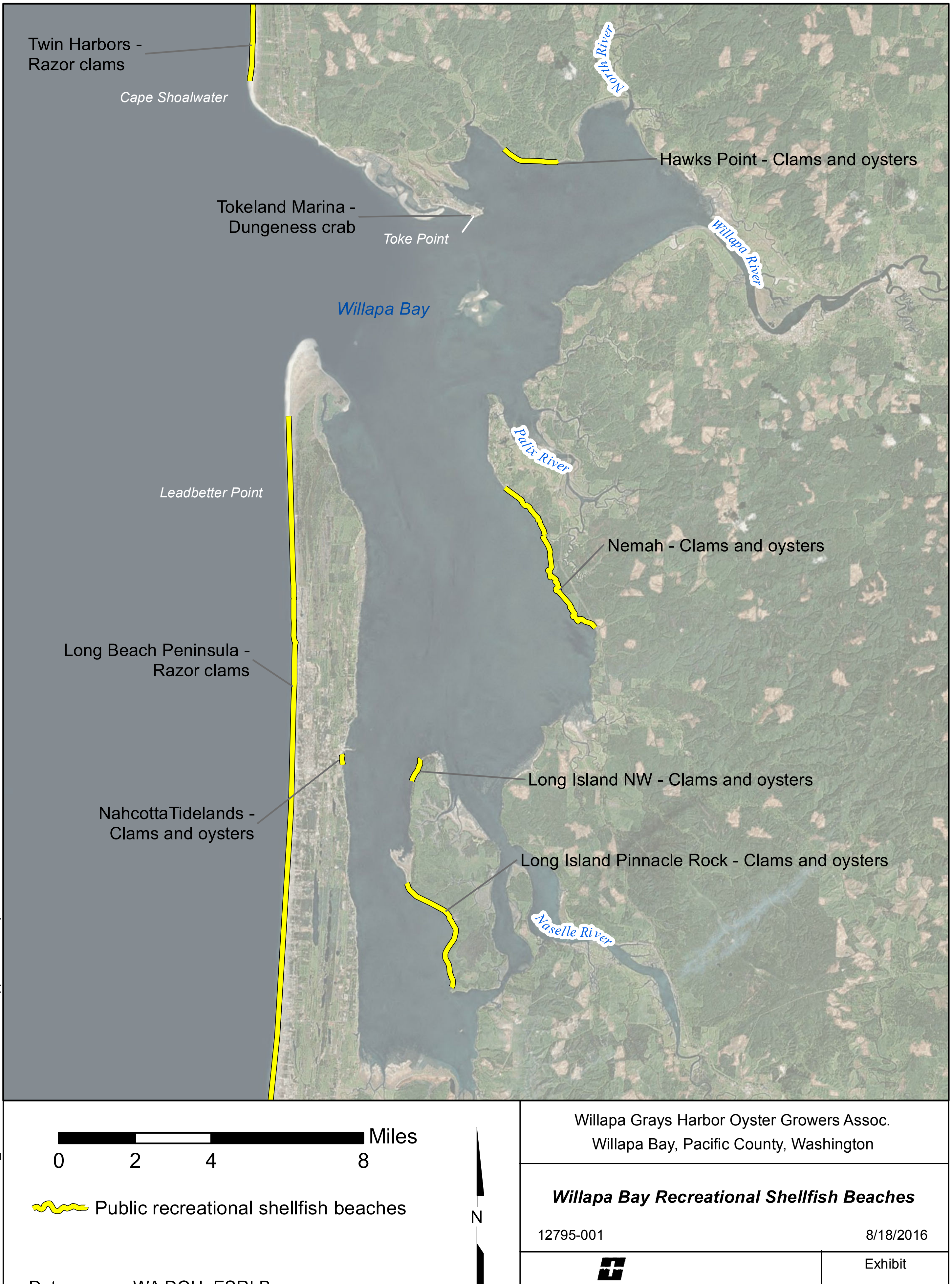
Oyster Beds in Grays Harbor

12795-001 8/18/2016

HARTCROWSER

Exhibit

B



Data source: WA DOH, ESRI Basemap

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Willapa Grays Harbor Oyster Growers Assoc.
Willapa Bay, Pacific County, Washington

Willapa Bay Recreational Shellfish Beaches

12795-001 8/18/2016

HARTCROWSER

Exhibit

C

Data source: WA DOH, ESRI Basemap

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Willapa Grays Harbor Oyster Growers Assoc.
Grays Harbor County, Washington

Grays Harbor Recreational Shellfish Beaches and Oyster Beds

12795-001

8/19/2016

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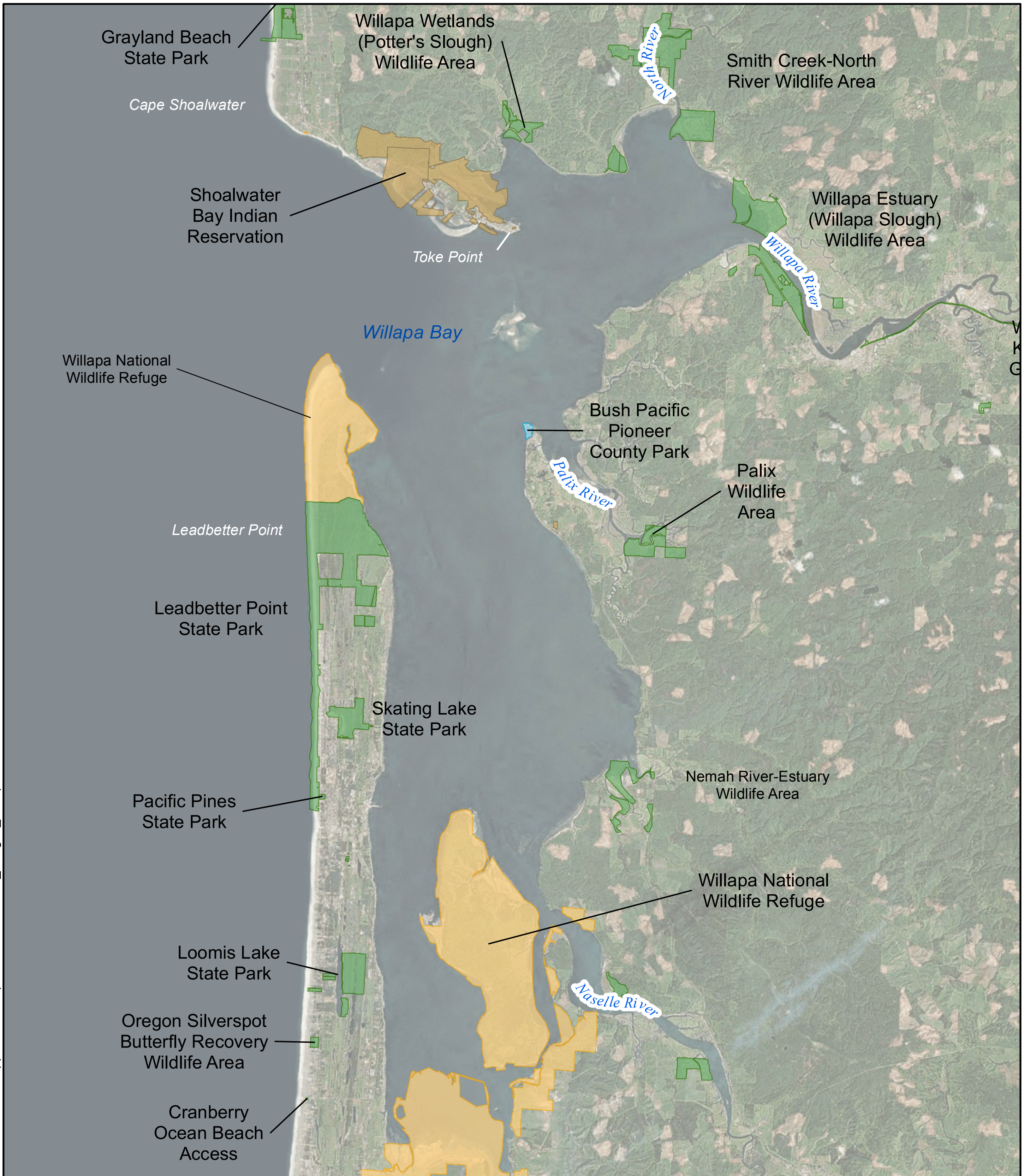
Exhibit

D



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County Government

State Government

Federal Government

Tribal Government

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Data source:
WDNR
ESRI Basemap

Willapa Grays Harbor Oyster Growers Assoc.
Willapa Bay, Pacific County, Washington

Willapa Bay Public Parks and Wildlife Areas

12795-001 8/24/2016

HARTCROWSER

Exhibit
E

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State Government

Federal Government

Tribal Government

Data source:
WDNR
ESRI Basemap

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Willapa Grays Harbor Oyster Growers Assoc.
Grays Harbor County, Washington

Grays Harbor Public Parks and Wildlife Areas

12795-001 8/24/2016

HARTCROWSER

Exhibit

F

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Exhibit G

Appendix A

Bird Checklists of the United States:
Willapa National Wildlife Refuge (USFWS 1991)

The U.S. Geological Survey (USGS), Northern Prairie Wildlife Research Center[1] maintains Bird Checklists of the United States that are grouped by geographic area. The checklist area for Willapa National Wildlife Refuge and the Columbia River Estuary includes: Willapa Bay and adjacent habitats west of Highway 101 and south of Highway 105, plus the Long Beach Peninsula; the Columbia River from Puget Island to the Pacific Ocean; and the Julia Butler Hansen Refuge for the Columbia whitetailed deer. The list of bird species reproduced below has been extracted from that source for only those sightings in Willapa Bay, the Long Beach Peninsula and the Columbia River, west on the Astoria-Megler Bridge.

Seasons

Spring	March through May
Summer	June through August
Fall	September through November
Winter	December through February

Relative Abundance

a – abundant	Species that are very numerous
c – common	Species that are nearly certain to be seen
u – uncommon	Species that are present but not certain to be seen
o – occasional	Species that are seen several time/year or locally
r – rare	Species seen at intervals of 2 to 5 years
*	Known to nest within the checklist area

Common Names	Seasonal Observations			
	Spring	Summer	Fall	Winter
LOONS				
Red-throated loon	c	-	c	c
Pacific loon	c	r	c	u
Common loon	c	r	c	u
GREBES				
Pied-billed grebe*	u	u	u	u
Horned grebe	c	r	c	c
Red-necked grebe	r	-	o	o
Western grebe	a	u	a	a

[1] The Northern Prairie Wildlife Research Center (NPWRC) is one of 18 science and technology centers within the USGS Biological Resources Discipline (BRD). The NPWRC is administratively positioned in the Central Region of the United States, and geographically located in the northern Great Plains. The main campus is in Jamestown, North Dakota. The mission of NPWRC is to provide the scientific information needed to conserve and manage the national's biological resources, with an emphasis on the species and ecosystems of the nation's interior.

Common Names	Seasonal Observations			
	Spring	Summer	Fall	Winter
FULMARS, PETRELS AND SHEARWATERS				
Northern fulmar	-	r	r	u
Pink-footed shearwater	-	-	r	-
Sooty shearwater	u	c	a	-
Short-tailed shearwater	-	-	-	o
Fork-tailed storm petrel	-	-	r	-
Leach's storm petrel*	-	-	r	-
PELICANS AND CORMORANTS				
Brown pelican	o	c	c	-
Double-crested cormorant*	c	c	c	c
Brandt's cormorant*	c	c	c	c
BITTERNS, HERONS AND EGRETS				
American bittern*	o	u	u	o
Great blue heron*	c	c	c	c
Great egret	o	-	o	-
Cattle egret	-	-	r	-
Green heron	r	r	r	-
WATERFOWL				
Tundra swan	-	-	u	u
Trumpeter swan	-	-	u	u
Greater white-fronted goose	o	-	o	o
Snow goose	o	-	o	o
Ross' goose	r	-	-	-
Emperor goose	r	-	o	r
Brant	a	o	c	c
Canada goose*	a	c	a	a
Wood duck*	u	u	u	-
Green-winged teal	c	r	c	c
Mallard*	c	c	c	c
Northern pintail	u	r	a	c
Blue-winged teal	u	r	u	-
Cinnamon teal*	u	u	u	-
Northern shoveler	u	r	u	o
Gadwall	u	r	u	u
Eurasian wigeon	-	-	o	o
American wigeon	c	r	a	c
Canvasback	u	-	u	u
Ring-necked duck	u	-	u	u
Tufted duck	-	-	-	r
Greater scaup	u	-	u	u
Lesser scaup	c	-	c	c
Harlequin duck	r	-	r	r
Oldsquaw	o	-	r	o
Black scoter	u	-	u	u

Common Names	Spring	Summer	Fall	Winter
	Seasonal Observations			
Surf scoter	c	o	c	c
White-winged scoter	c	o	c	c
Common goldeneye	u	-	u	c
Barrow's goldeneye	r	-	-	r
Bufflehead	c	-	c	c
Hooded merganser*	u	o	u	u
Common merganser*	c	u	u	u
Red-breasted merganser	c	r	c	c
Ruddy duck	o	-	u	u
VULTURES				
Turkey vulture	u	u	u	r
OSPREY, KITES, EAGLES AND HAWKS				
Osprey*	u	u	u	r
White-tailed kite	o	u	o	o
Bald eagle*	u	u	u	u
Northern harrier*	c	c	c	c
Sharp-shinned hawk	u	r	u	u
Cooper's hawk	u	r	u	u
Northern goshawk	r	-	r	r
Red-tailed hawk*	c	c	c	c
Rough-legged hawk	u	-	u	u
FALCONS				
American kestrel	u	r	u	u
Merlin	u	-	u	u
Peregrine falcon	u	-	u	u
Gyrfalcon	-	-	r	r
GALLINACEOUS BIRDS				
Ring-necked pheasant*	u	u	u	u
Blue grouse*	u	u	u	r
Ruffed grouse*	u	u	u	u
Wild turkey	r	r	r	r
Northern bobwhite*	u	u	o	o
RAILS				
Virginia rail*	u	u	u	r
Sora	r	-	r	-
American coot	u	-	u	c
PLOVERS				
Black-bellied plover	c	u	a	c
American golden plover	r	r	u	r
Snowy Plover*	u	u	u	r
Semipalmated plover	c	c	c	r

Common Names	Spring	Summer	Fall	Winter
	Seasonal Observations			
Killdeer*	u	u	c	u
OYSTERCATCHERS				
American oystercatcher*	u	u	u	-
SHOREBIRDS				
Greater yellowlegs	c	u	c	c
Lesser yellowlegs	-	-	r	-
Willet	r	-	o	o
Wandering tattler	u	o	u	-
Spotted sandpiper	u	o	u	-
Whimbrel	c	o	c	-
Long-billed curlew	u	-	u	o
Bar-tailed godwit	-	-	o	-
Marbled godwit	u	o	u	r
Ruddy turnstone	c	o	c	r
Black turnstone	u	u	u	u
Surfbird	c	r	c	r
Red knot	c	-	u	-
Sanderling	a	c	a	c
Semipalmated sandpiper	o	r	-	-
Western sandpiper	a	a	a	c
Least sandpiper	c	c	a	u
Pectoral sandpiper	-	-	c	-
Sharp-tailed sandpiper	r	-	u	-
Dunlin	a	u	a	a
Stilt sandpiper	-	-	r	-
Ruff	-	-	r	-
Short-billed dowitcher	a	a	c	-
Long-billed dowitcher	u	r	c	u
SNIPE				
Common snipe	c	r	c	u
PHALAROPES				
Wilson's phalarope	-	-	r	-
Red-necked phalarope	u	o	u	-
Red phalarope	r	r	o	-
JAEGERS				
Parasitic jaeger	r	r	u	-
GULLS AND TERNS				
Bonaparte's gull	c	u	c	r
Heermann's gull	o	c	c	-
Mew gull	c	r	c	c
Ring-billed gull	c	u	c	u

Common Names	Spring	Summer	Fall	Winter
	Seasonal Observations			
California gull	c	u	a	u
Herring gull	-	-	-	r
Thayer's gull	-	-	-	r
Western gull*	c	c	c	c
Glaucous-winged gull*	c	c	c	c
Black-legged kittiwake	u	r	u	u
Sabine's gull	r	r	r	-
Caspian tern*	c	c	c	-
Common tern	u	r	u	-
Arctic tern	r	-	r	-
SEABIRDS				
Common murre	u	c	c	u
Pigeon guillemot*	c	c	u	r
Marbled murrelet*	u	u	u	u
Ancient murrelet	-	-	r	r
Cassin's auklet	-	-	r	r
Rhinoceros auklet	o	u	o	o
Tufted puffin	o	u	o	o
Horned puffin	-	-	-	o
DOVES				
Rock dove*	u	u	u	u
Band-tailed pigeon*	c	c	c	-
Mourning dove	r	r	r	-
OWLS				
Barn owl*	u	u	u	u
Western screen owl*	u	u	u	u
Great horned owl*	u	u	u	u
Snowy owl	-	-	-	r
Northern pygmy owl*	u	u	u	u
Burrowing owl	r	-	r	r
Barred owl*	u	u	u	u
Long-eared owl	r	-	r	r
Short-eared owl	u	o	u	u
Northern saw-whet owl*	u	u	u	u
GOATSUCKERS				
Common nighthawk*	r	u	u	-
SWIFTS				
Vaux's swift*	c	c	c	-
HUMMINGBIRDS				
Anna's hummingbird	-	-	-	r
Rufous hummingbird*	a	a	o	r

Common Names	Seasonal Observations			
	Spring	Summer	Fall	Winter
KINGFISHERS				
Belted kingfisher*	u	u	u	o
WOODPECKERS				
Red-breasted sapsucker	u	-	u	u
Downy woodpecker*	u	u	u	u
Hairy woodpecker*	u	u	u	u
Northern flicker*	c	c	c	c
Pileated woodpecker*	u	u	u	u
FLYCATCHERS				
Olive-sided flycatcher*	c	c	o	-
Western wood-pewee*	u	u	o	-
Willow flycatcher*	u	u	o	-
Pacific-slope flycatcher*	c	c	u	-
LARKS				
Horned lark*	u	u	u	o
SWALLOWS				
Tree swallow*	c	c	u	o
Violet-green swallow*	c	c	u	o
Northern rough-winged swallow*	u	u	o	-
Cliff swallow*	c	c	o	-
Barn swallow*	c	a	o	-
JAYS, MAGPIES AND CROWS				
Gray jay	o	o	o	o
Stellar's jay*	u	u	c	u
American crow*	c	c	c	c
Common raven*	u	u	u	u
CHICKADEES AND TITMICE				
Black-capped chickadee*	c	c	c	c
Chestnut-backed chickadee*	c	c	c	c
BUSHTITS				
Bushtit*	o	r	o	o
NUTHATCHES				
Red-breasted nuthatch	u	r	u	u
CREEPERS				
Brown creeper*	u	u	u	u

Common Names	Seasonal Observations			
	Spring	Summer	Fall	Winter
WRENS				
Bewick's wren*	u	u	u	u
Winter wren*	c	c	c	c
Marsh wren*	c	c	c	c
KINGLETS, BLUEBIRDS AND THRUSHES				
Golden-crowned kinglet*	c	c	c	c
Ruby-crowned kinglet*	c	r	c	u
Western bluebird	r	-	r	-
Mountain bluebird	r	-	r	-
Townsend's solitaire	o	r	r	-
Swainson's thrush*	c	c	u	-
Hermit thrush	u	-	u	u
American robin*	c	c	c	c
Varied thrush*	c	u	c	c
WAGTAILS AND PIPITS				
American pipit	-	-	o	-
WAXWINGS				
Cedar waxwing*	u	c	u	r
SHRIKES				
Northern shrike	o	-	u	u
STARLINGS AND MYNAS				
European starling*	c	c	c	c
VIREOS				
Solitary vireo*	r	-	r	-
Hutton's vireo*	u	u	u	u
Warbling vireo*	u	u	o	-
Orange-crowned warbler*	c	c	u	-
Yellow warbler*	u	u	r	-
Yellow-rumped warbler*	c	u	u	c
Black-throated gray warbler	c	c	u	-
Townsend warbler	c	-	u	u
Hermit warbler	r	r	-	-
Palm warbler	-	-	r	r
MacGillivray's warbler	r	r	-	-
Common yellowthroat*	c	c	u	-
Wilson's warbler	c	c	u	-
TANAGERS				
Western tanager*	u	u	o	-

Common Names	Seasonal Observations			
	Spring	Summer	Fall	Winter
GROSBEAKS AND BUNTINGS				
Black-headed grosbeak*	u	u	r	-
TOWHEES AND SPARROWS				
Rufous-sided towhee*	u	u	c	c
Chipping sparrow	r	-	r	-
Savannah sparrow*	c	c	u	-
Fox sparrow	u	-	u	u
Song sparrow*	c	c	c	c
Lincoln's sparrow	r	-	r	-
White-throated sparrow	o	o	-	-
Golden-crowned sparrow	c	-	c	c
White-crowned sparrow*	c	c	c	u
Dark-eyed junco*	c	c	c	c
Lapland longspur	r	-	c	r
Snow bunting	-	-	o	o
BLACKBIRDS, MEADOWLARKS, ORIOLES				
Red-winged blackbird*	c	c	c	c
Western meadowlark*	u	u	u	u
Yellow-headed blackbird	r	-	-	-
Brewer's blackbird*	c	c	u	u
Brown-headed cowbird*	c	c	u	r
FINCHES				
Purple finch*	c	c	u	u
House finch*	c	c	c	c
Red crossbill*	u	c	u	u
Common redpoll	-	-	-	r
Pine siskin*	c	o	c	c
American goldfinch*	u	c	c	r
WEAVER FINCHES				
House sparrow*	c	c	c	c

Appendix A, *continued*

Birds of Willapa Bay and Grays Harbor (WDF and WDOE, June 1985).

Explanation of Symbols

Breeding: * - (after species name) Known to breed regularly within Willapa Bay or Grays Harbor.

References: - Wahl, R. and R. Paulson. 1981. A Guide to Bird Finding in Washington. Whatcom Museum Press, Bellingham, WA.
- Willapa Bay National Wildlife Refuge Checklist and Widrig, R. 1980. The Birds and Plants of Long Beach Peninsula.

Habitats: SW - open salt water
SS - sandy shore
FW - fresh water (including marsh and shore)

Abundance: (in columns under Habitats and Seasons)
A - abundant
C - common; often seen or heard in appropriate habitats
U - uncommon; usually present but not seen or heard on every visit to appropriate habitats
R - rare; present in appropriate habitats only in small numbers and seldom seen or heard

Seasons: S - Spring F - Fall
S - Summer W - Winter

	Habitats SW	SS	FW	Seasons S	S	F	W
GAVIIDAE							
Common Loon	C		U	C	C	C	C
Arctic Loon	C		R	C	U	C	U
Red-throated Loon	C			C	U	R	C
PODICIPEDIDAE							
Red-necked Grebe	C		U	U		U	U
Horned Grebe	C		U	C	R	C	C
Western Grebe	C		C	A	U	A	A
Pied-billed Grebe	U		C	U	U	U	U
PROCELLARIIDAE							
Sooty shearwater	C			U	C	A	
PELECANIDAE							
Brown Pelican	R				R	U	
PHALACROCORACIDAE							
Double-crested Cormorant	C		U	C	C	C	C
Brandt's Cormorant	C			C	C	C	C
Pelagic Cormorant	C			C	C	C	C
ARDEIDAE							
Great Blue Heron		C	C	C	C	C	C
Great Common Egret	U			R		R	
American Bittern			C	R	R	U	R
ANATIDAE							
Whistling Swan			C			C	C
Trumpeter Swan						C	C
Canada Goose	U		C	A	C	A	C
Brant	C			C		U	C
White-fronted Goose	U		R	U		U	R
Snow Goose				R		R	R
Mallard	C		C	C	C	C	C
Gadwall	U		C	C	R	C	C
Pintail	C		C	C	U		C
Green-winged Teal	C		C	C	U	C	U
Cinnamon Teal	R		C	R		R	R
European Widgeon	R		R	R		R	R
American Widgeon	C		C	C	R		C
Shoveler	C		C	U	R	U	C
Redhead	R		C			R	U
Ring-necked Duck	R		C	U		C	U
Canvasback	C		C	C		C	C
Greater Scaup	C		C	C	U	C	C
Lesser Scaup	C		C	U	R	U	U
Common Goldeneye	C		C	U		U	C
Barrow's Goldeneye	C		C	R		R	R
Bufflehead	C		C	C	R	C	A
Oldsquaw	U		R	U	R	R	U
White-winged Scoter	C		R	C	U	A	A
Surf Scoter	C		R	C	U	C	A
Common Scoter	U			U	R	U	U
Ruddy Duck	U		C	U	R	U	U
Hooded Merganser	R		U	U	R	U	U
Common Merganser	U		U	U	U	U	C
Red-breasted Merganser	C		R	C	U	C	C
ACCIPITRIDAE							
Sharp-shinned Hawk				U		U	C
Cooper's Hawk				U	U	U	C
Red-tailed Hawk				U	U	C	C
Bald Eagle		C		U	U	U	U
Marsh Hawk			C	U	U	C	C
PANDIONIDAE							
Osprey		U	U		U		
FALCONIDAE							
Peregrine Falcon		R		U		U	R
Merlin Pigeon Hawk				U		U	U
American Kestrel				U		U	R
GRUIDAE							
Sandhill Crane			U			R	

	Habitats			Seasons			
	SW	SS	FW	S	S	F	W
RALLIDAE							
Virginia Rail			C	U	U	U	U
American Coot	C	C		U	R	U	U
HAEMATOPODIDAE							
Black Oystercatcher					R		R
CHARADRIIDAE							
Semipalmated Plover		C	R	C	C	C	R
Snowy Plover		U		U	U	U	R
Killdeer		U	C	U	U	C	U
American Golden Plover		U	R	R	R	U	R
Black-bellied Plover		C	U	C	C	C	C
Surfbird				U	R	U	R
Ruddy Turnstone		U	R	U		U	R
Black Turnstone		U		U		U	C
SCOLOPACIDAE							
Common Snipe		U	C	C	R	C	U
Long-billed Curlew		R	R	U	U	U	R
Whimbrel		C	R	C	C	C	
Spotted Sandpiper		C	C	U	R	U	
Wandering Tattler				U	U	U	
Willet		R	R	R	R	U	R
Greater Yellowlegs		C	C	C	U	C	U
Lesser Yellowlegs		U	C	C	U	C	C
Red Knot		C	R	C	U	U	
Sharp-tailed Sandpiper		R		R		U	
Pectoral Sandpiper		C	C			C	
Baird's Sandpiper		U	C	R	R	U	
Dunlin		C	R		U		
Short-billed Dowitcher		C	R	U		U	
Long-billed Dowitcher		C	C		U		
Western Sandpiper		C	C		C		
Buff-breasted Sandpiper		R			R	R	
Marbled Godwit		R	R	R		U	
Sanderling		C	U	C	U	C	
Least Sandpiper		C	C		U		
PHALAROPODIDAE							
Red Phalarope	U	R		R		R	
Wilson's Phalarope		U	C	R			
Northern Phalarope	C	U	C	U		U	
STERCORARIIDAE							
Parasitic Jaeger	C				R	U	U

	Habitats			Seasons			
	SW	SS	FW	S	S	F	W
LARIDAE							
Glaucous Gull	R	R	R	U	U		U
Glaucous-winged Gull	C	C	U	C	U	C	C
Western Gull	C	C		C	U	C	C
Herring Gull	C	C	U	C	U	C	
Thayer's Gull	C	C		U		U	U
California Gull	C	C	C	U	C	C	U
Ring-billed Gull	U	U	C	C	U	C	C
Mew Gull	C	C	U	C	R	C	C
Bonaparte's Gull	C	C	C	C		C	U
Heermann's Gull	C	C		U	U	C	C
Black-legged Kittiwake	C			U		C	U
Common Tern	C	C		R	U	C	
Arctic Tern	U	R		R		U	
Caspian Tern	U	U	U	U		U	
ALCIDAE							
Common Murre	C			C	U	C	
Pigeon Guillemot	C			C	U	C	
Marbled Murrelet	C			R			R
Rhinoceros Auklet	C			R			R
STRIGIDAE							
Gread Horned Owl				C	C	C	C
Short-eared Owl				U	U	U	U
ALCEDINIDAE							
Belted Kingfisher		C	C	C	C	C	C
CORVIDAE							
Common Raven			C	R	R	R	R
Crow - Common and Northwestern		C	C	C	C	C	C

Exhibit H: Potential Effects of Imidacloprid Treatments on Birds

The SEPA (State Environmental Policy Act) EIS (Environmental Impact Statement) discussed the birds of Willapa Bay and Grays Harbor in some detail, and specifically examined potential impacts of imidacloprid spraying. The potential for negative impacts was deemed low for a variety of reasons:

- The very low toxicity of imidacloprid to birds. The EIS reviewed studies showing that concentrations of imidacloprid below 150 milligrams per kilogram (mg/kg) are generally non-toxic to birds (Gervais et al. 2010), and that no direct or indirect effect of imidacloprid application had been found on bird species in Willapa Bay or Grays Harbor (McGaughey et al. 2013).
- Seasonal timing that would limit potential exposure. Many birds are present in Willapa Bay and Grays Harbor during a specific time of the year. Birds present as overwintering species, or that pass through in spring migrations (April-May) are likely to have a lower potential for exposure to imidacloprid than species that are year-round residents, or that tend to use these estuaries in the summer. The EIS notes that the majority of birds that use these estuaries are migrating through. Anecdotally, WGHOGA growers have observed that seagulls and American crows are often the only species of birds present on beds that have recently been treated with imidacloprid, perhaps due, in part, to their tolerance of the human presence and disturbance immediately before and after treatment (WGHOGA pers. comm.).
- Habitat use patterns that would limit potential exposure. Many birds use only deeper water habitats (e.g., marbled murrelets), barrier beaches (e.g., snowy plovers), salt marshes, or upland vegetation where the potential for imidacloprid exposure is minimal. Many other shorebirds and waterfowl concentrate their use in the shallowest portions of Willapa Bay and Grays Harbor for the simple reason that these areas have a longer exposure during low tides than do deeper areas. Many of these species use areas where imidacloprid may be sprayed, but a majority of their feeding and habitat use would be outside such areas, limiting exposure.
- Rapid dilution and breakdown of imidacloprid after application. A number of studies are cited to show imidacloprid dilution to non-toxic levels on the first tide following application, and an exponential decline in sediments over 14-28 days. The transitory nature of imidacloprid in the estuaries reduces potential exposure to birds.

The EIS also evaluated potential benefits of imidacloprid applications. The EIS reviewed a number of studies that documented that high densities of burrowing shrimp were associated with lower or much lower numbers of other invertebrate species than areas with low shrimp densities (Chapter 3.1, section titled *Interaction of Burrowing Shrimp with Other Mudflat Organisms*). To the extent shrimp reduce the ability of other invertebrate species to colonize and grow, it reduces prey for bird species that consume these animals.

One example is the amphipod *Corophium*, a relatively large and abundant (up to 40,000/m^2) species that is available as an infaunal organism near the surface of the sediment during low tide. Birds as small as sandpipers, with bill lengths of 75-100 mm, are able to find and consume this prey. Qualitative studies have confirmed that areas with high *Corophium* abundance are attractive to shorebirds in Willapa Bay, and conversely, that areas with low abundance often have few shorebirds (Dr. Richard Wilson, pers. comm.)

The EIS also examined the effects of high shrimp densities on vegetation. It cited literature showing high shrimp densities have been found to reduce or eliminate the presence of eelgrass (see EIS Chapter 3.1, section titled *Interactions of Burrowing Shrimp and Eelgrass*). Waterfowl that feed on eelgrass (e.g., black brant) are therefore also likely to experience negative impacts in areas where burrowing shrimp densities are high.

Dr. Richard Wilson, of Bay Center Mariculture, has studied sediments from the surface of Willapa Bay in areas with high and low densities of burrowing shrimp. Using high resolution microphotographs, he has examined sediments for the presence of food organisms that could be used to support epibenthic and infaunal invertebrates. In low shrimp settings he has found the surface sediment particles are intermixed with a biofilm of diatoms and other plankton (see microphotographs at https://www.flickr.com/photos/76798465@N00/28665041926/in/album-72157671681119915/). By contrast, many sediments with high shrimp densities lack this biofilm, and are dominated by inorganic particles (see microphotographs at https://www.flickr.com/photos/76798465@N00/28665039106/in/album-72157671681119915/). When sediments from the two types of areas are compared, the biggest difference is that high shrimp locations are dominated by sand sized particles, and generally have very low levels of silt and clay. Based on this difference, Dr. Wilson believes that the small sediment components of silt and clay are important to help stabilize the sediments, and without them the resulting unstable fine sands prevent the development of a diatom biofilm. Regardless of whether this hypothesis is correct, his work points out a real difference in food resources to invertebrates that likely helps to explain why high shrimp densities are often associated with decreases in other invertebrate species. And, as noted above, reduced invertebrate resources represent a negative impact to many shorebird and waterfowl.

Stakeholders raised concerns about potential impacts to birds during the public review of the EIS, and in subsequent correspondence with Ecology (e.g., Audubon Washington letter of July 7, 2016). Although some of these comments questioned whether spraying could impact birds by reducing the availability of burrowing shrimp as prey, the small percentage of Willapa Bay and Grays Harbor that would be sprayed (a maximum of 0.7 percent and 0.02% respectively, of the area of these estuaries) ensures that if any bird species do feed on burrowing shrimp they would have extensive, untreated acreage for foraging. Another raised concern was that birds may forage on treated areas, and therefore be exposed to imidacloprid, either directly through water and sediment contact, or through ingestion of imidacloprid-containing prey. An important mitigating factor to this potential exposure pathway is the very short period in which imidacloprid remains in the environment. Repeated field trials reviewed in the EIS have documented that water concentrations of imidacloprid fall below biologically toxic levels with the first incoming tide, and sediment concentrations show an approximately negative exponential decline in imidacloprid concentrations, with residues below biologically toxic levels in 14-56 days. Similarly, epibenthic invertebrates, which are a primary food source for many shorebirds (e.g., sanderling, *Calidris alba*), are similarly dispersed with the tides, making any ingestion-based pathway to exposure highly unlikely. Species that forage for invertebrates in the sediment may ingest prey containing imidacloprid. Such exposures should be short-term, as prey killed by imidacloprid rapidly deteriorate into an indigestible state following treatment. Also, the very low toxicity of imidacloprid is expected to prevent the occurrence of negative impacts in birds even if they do forage on invertebrates containing imidacloprid.

Imidacloprid has been sprayed experimentally in Willapa Bay over a number of years. Carbaryl, a much more toxic pesticide, has been sprayed in both Willapa Bay and Grays Harbor for over 50 years. These sprayings offer an empirical test of whether shorebirds are at risk of acute or sub-lethal effects of imidacloprid spraying. No impacts to birds have been noted (e.g., mortality, disoriented behavior, etc.) from treatment of shellfish beds with either imidacloprid or carbaryl. In addition, as noted in the Audubon Washington letter, Willapa Bay and Grays Harbor "support a diverse array of birds and marine wildlife, including exceptional numbers of migratory shorebirds" and offer "a vital wintering area for waterfowl and shorebirds." This outstanding diversity and support of shorebird populations has occurred over five decades of carbaryl spraying to control burrowing shrimp with no apparent negative impacts, strong evidence that limited spaying of the less toxic imidacloprid proposed in the permit will not harm birds in these estuaries.

A summary of ten years of research (2006 to 2015) on the efficacy of imidacloprid for management of burrowing shrimp infestations on shellfish grounds

Kim Patten
Washington State University Long Beach Research and Extension Unit

Introduction: There has been an extensive effort to develop alternative controls for burrowing shrimp on shellfish beds. Those efforts resulted in imidacloprid being registered by EPA for burrowing shrimp control. Field efficacy of imidacloprid applied by the shellfish industry, however, has been variable and not consistent. There are several reasons for this variability in efficacy. One is that it is a very difficult pest to control. The other is that the monitoring protocol used by the industry was not designed to provide data on efficacy. Rather it was intended to indicate if the burrowing shrimp density of a bed in the spring was above the economic threshold (> 10 burrows/m^2) to warrant spraying with carbaryl in the summer. Monitoring consists of a dozen or so counts made in the spring from a single egress point per site. In comparison to the summer counts, these spring counts are done when there is less burrow activity, more wave action minimizing observable burrows, and less eelgrass coverage to obscure the burrows during counting.

To properly assess efficacy, a large number of burrow counts should be made immediately before treatment and ~ ½ to 1 month after treatment. Comparable methods of measurement should be used at the same or similar locations on the beds. The only data available of this type is that collected by WSU over that past decade. Most of this data is from small research trials conducted under a 1 acre EUP. However, some of the later experiments and conditions were over larger commercial sites. To provide a more comprehensive overview of efficacy, the data from WSU's progress reports from the previous 10 years have been summarized for this report. They were compiled into three tables of varying application conditions. Tables and figures from those original reports are provided in Appendix 1.

Results: A range of efficacy under normal conditions is provided in Table 1. Without eelgrass or water on the site, efficacy of imidacloprid at 0.5 lbs ai/ac ranges from 40 to 80%. Zero control and 100% control were also frequently noted, but those results were outliers. Efficacy varied considerably under any particular sediment type and condition depending on when the product was applied in relationship to the tidal conditions. Imidacloprid, either the 0.5% G or 2F, applied after the sand had dried, generally resulted in poorer efficacy than if the product was applied just as the tide went off the ground. These perfect application conditions are very difficult to replicate with large-scale applications over many beds (traditional aerial applications). Smaller targeted applications would be expected to result in better control.

Efficacy of imidacloprid under more difficult treatment conditions, such as thick eelgrass or on sites that don't go dry, is presented in Tables 2 and 3. Reduced efficacy occurred under these conditions. Results from alternative treatment methods to improve efficacy under these conditions are also presented in Tables 2 and 3. Controlling burrowing shrimp in areas of thick eelgrass or flowing water will be a challenge. The use of several application methods on a single bed might be needed to achieve acceptable control across the entire bed. Table 1 in Appendix 2 provides an example of the type of treatments that would be recommended across several locations within a bed. Other timings and application methods will need to be more fully vetted, but have not been possible without a NPDES permit. Examples are pretreating sites infested with *Z. japonica* with imazamox 2-3 months prior to treatment with imidacloprid, or hand application of the granular product in 12” to 18” of shallow water in sites covered with thick eelgrass.

Conclusion: Compared to the previous use of carbaryl at 8 lbs ai/ac, achieving good efficacy with broadcast-applied imidacloprid at 0.5 lbs/ac across a range of conditions found on shellfish beds in Willapa Bay requires adaptive management approaches until the optimal method can be identified. An individual bed may require a specific IPM plan that details separate application methods for each of the varying conditions on the bed. Details on a draft recommendation for an IPM treatment plan are provided in Appendix 2. Application of recommendations from this plan will need to be made to larger sites and modified over time.

Table 1. Efficacy of imidacloprid at ≤ 0.5 lbs ai/ac under normal tidal conditions

Condition	Formulation	Application conditions	Expected range of control (%)found under experimental conditions	Tables referenced in appendix	Figures referenced in appendix
Sand, no or minimal eelgrass	2F	Broadcast, no standing water	60 to 80*	6, 8, 10, 17, 18, 19, 20, 21	1, 11, 19
Sand, no or minimal eelgrass	0.5G	Broadcast, no standing water	40 to 70**	12, 13, 14, 17, 18, 19	6, 8, 11,13
Silt, no or minimal eelgrass	2F	Broadcast, no standing water	50 to 70*	8, 10, 12, 17, 18, 21	
Silt, no or minimal eelgrass	0.5G	Broadcast, no standing water	40 to 70 **	13, 15, 16	10, 12, 13

* lower if applied to dry beds, higher if applied just as tidal water is going off bed.

** much lower if applied to beds, higher if applied in shallow water just as tidal water is going off bed.

Table 2. Efficacy of imidacloprid at ≤ 0.5 lbs ai/ac in locations that don't fully dewater.					
Condition	Formulation	Application conditions	Expected range of control (%) found under experimental conditions	Tables referenced in appendix	Figures referenced in appendix
Sand	2F	Broadcast, tide out, no standing water	60 to 80*	6, 8, 10, 17, 18, 19, 20, 21	1, 11, 19
Sand	0.5G	Broadcast, tide out, no standing water	40 to 70**	12, 13, 14, 17, 18, 19	6, 8, 11,13
Sand	2F	Broadcast, tide out, shallow standing water with no outflow	60***		
Sand	2F	Broadcast, tide out or going out, shallow or deep swale with constant flow of water	0****		
Sand	0.5G	Broadcast, tide out, shallow standing water with no outflow	70		19
Sand	0.5G	Broadcast, applied in shallow water 3" to 60" as tide is going out	30 to 80 *****	17, 21	9, 14, 15
Sand	2F	Injected via spikewheel - 4" to 6" depth, shallow or deep swale with constant flow of water	70 to 90	1, 2, 3, 4, 5, 6, 8,10	2, 3, 4

* lower if applied to dry beds, higher if applied just as tidal water is going off bed.
** much lower if applied to beds, higher if applied in shallow water just as tidal water is going off bed.
*** WSU data from small pools, not large sites. Results have not been provided in any progress report.
**** WSU observations and data not contained in any progress report
***** lower efficacy in deeper water

Table 3. Efficacy of imidacloprid ≤ 0.5 lbs ai/ac under conditions of moderate to thick densities of eelgrass, mainly *Z. japonica*.					
Condition	Formulation	Application conditions	Expected range of control (%) found under experimental conditions	Tables referenced	Figures referenced
Sand or silt, thick eelgrass (Zj or Zm)	2F	Broadcast, tide out, no standing water	0 to 70*	6, 17, 18, 19, 21, 22	1, 16, 17, 18, 19
Sand covered with eelgrass (Zj)	2F	Broadcast, tide just going off, 3" to 18" of water.	0 to 40**	19	NA
Sand covered with eelgrass (Zj)	0.5G	Broadcast, tide just going off, 3" to 40" of water.	30 to 70***	12, 17	9, 14
Sand covered with eelgrass (Zj)	2F	Injected via spikewheel - 4" to 6" depth	NA****	6, 7, 8, 9, 10	4
Sand covered with eelgrass (Zj)	2F	Injected by hand - 18"	95****	22	NA
Sand covered with eelgrass (Zj)	2F	Site was pretreated with imazamox to remove Japanese eelgrass prior to treatment. Broadcast, tide out, no standing water	60 to 90	11	18
Sand covered with eelgrass (Zj)	2F	Site was disked after treatment to cut up the eelgrass root zone and incorporate imidacloprid.	30 to 60	NA	16, 17

*Highly variable control. Source of variation is likely the density of eelgrass.
** Sections of these sites were treated in flowing water. The lower efficacy is associated with those locations.
*** Density of eelgrass, depth of water, size of plots are all sources of variation. Not enough large-scale plots on these types of sites to assure confidence in the efficacy range. Lower range of efficacy might be more typical.
**** Only minimal trials of this have been conducted on very small areas.
**** Experiments have not been conducted under these conditions, data not available (NA).

Appendix 1. Efficacy tables and figures from 10 years of progress reports to the Washington State Commission for Pesticide Registration, WDFW and/or USDA.

No effort has been made to standardize format of the data. Prior to 2011, much of the work with the 2F formulation of imidacloprid was done at the 2 lbs ai/ac rate. Those results were left in the data in the Appendix, but are not part of the expected efficacy range presented in Tables 1, 2, & 3.

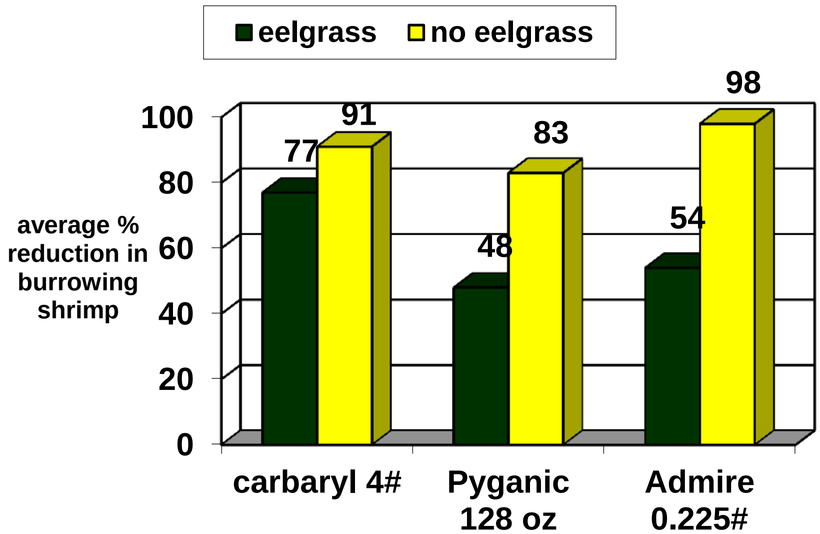


Figure 1 - 2006. Average reduction of burrowing shrimp burrow density over eight experiments with the application of three insecticides to tidal sand flats with and without eelgrass cover.

Table 1. Field screening of pesticides for efficacy on burrowing shrimp using spikewheel injection from a barge in 2006 on sandy sediment.

Compound	Mean burrow (#/m2 ± std. err.) count 1 month post treatment
Imidacloprid 0.5 Lbs ai/A	0 ± 0
Imidacloprid 0.2 Lbs ai/A	0.7 ± 0. 3
Imidacloprid 0.1 Lbs ai/A	6 ± 2
Carbaryl 3 lbs ai/A	3 ± 1
Mustard cake 4000 lbs/A	32 ± 5
Pyganic 128 oz/A	45 ± 6
Habenero 2 qt/A	61 ± 3
Mustang 0.01 lbs ai/A	37 ± 5
Methoprene 1 lb/A	32 ± 2
Ecozone 20 lbs/A	49 ± 9
Sulfur 80 lbs/A	51 ± 3

Table 2 - 2006. The efficacy of various rates of imidacloprid applied across a range of timings and conditions using the Spikewheel applicators on sandy sediment.							
	Burrows (mean #/m^2± std. error) 2 weeks after treatment[1]						
	Site						
Treatment rate	Swwdfw[2]	Swms[3]	Sw15[4]	Sw13[5]	Sw12[6]	Sw9[7]	Sw20[8]
Control	8.7±0.7	33.5±2.0	105±4.7	72.4±3.7	9.7±3.5	81± 2.0	116±8
Imidacloprid 0.1 lb ai/ac						23±8.0	
Imidacloprid 0.2 lb ai/ac				12.2±2.6		5.7±2.4	
Imidacloprid 0.4 lb ai/ac	1.0±0.2	8.1±1.7	6.5±1.5	2.4±0.7	0.7±0.3	0.25±0.2	2.2±0.9
Imidacloprid 0.8 lb ai/ac		4.2±2.0					
Sevin 3 lb ai/ac					2.7±2.2	14.7±2.0	
Sevin 4 lb ai/ac							31 ±3

[1] Date of counts varied by sites ranging from 1 to 4 weeks after treatment; 2 weeks was the average.
[2] Spikewheel WDFW applied September 12, 2006, silt
[3] Spikewheel MS applied September 12, 2006, silt
[4] Spikewheel 15 applied August 30, 2006, sand
[5] Spikewheel 13 applied August 23, 2006, sand
[6] Spikewheel 12 applied August 8, 2006, sand
[7] Spikewheel 9 applied July 28, 2006, sand
[8] Spikewheel 20 applied Oct 20, 2006, sand

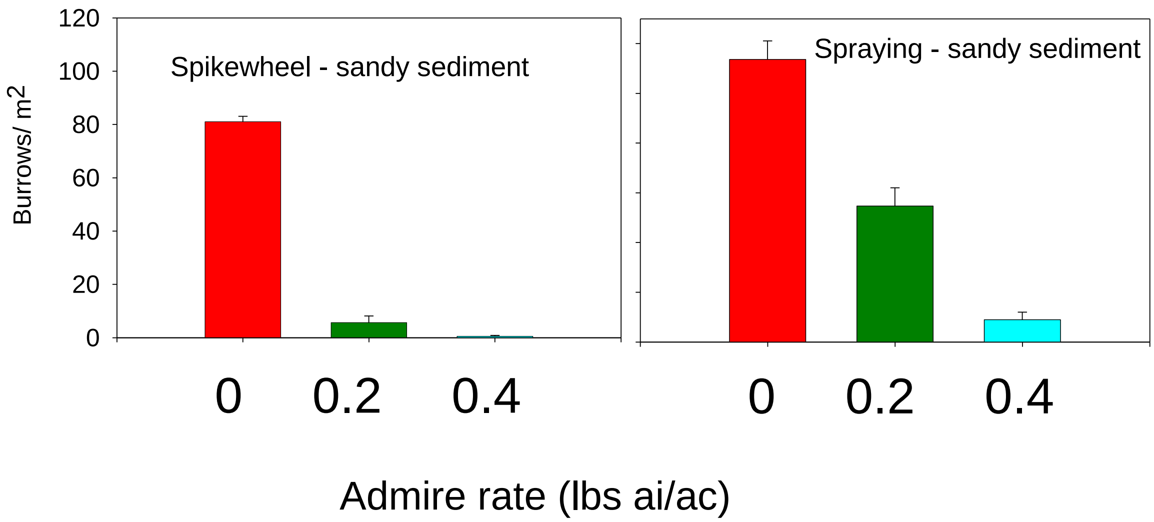


Figure 3 - 2006. Comparative efficacy of low rates of imidacloprid (Admire) for burrowing shrimp control from injection and broadcast spraying in sandy sediment.

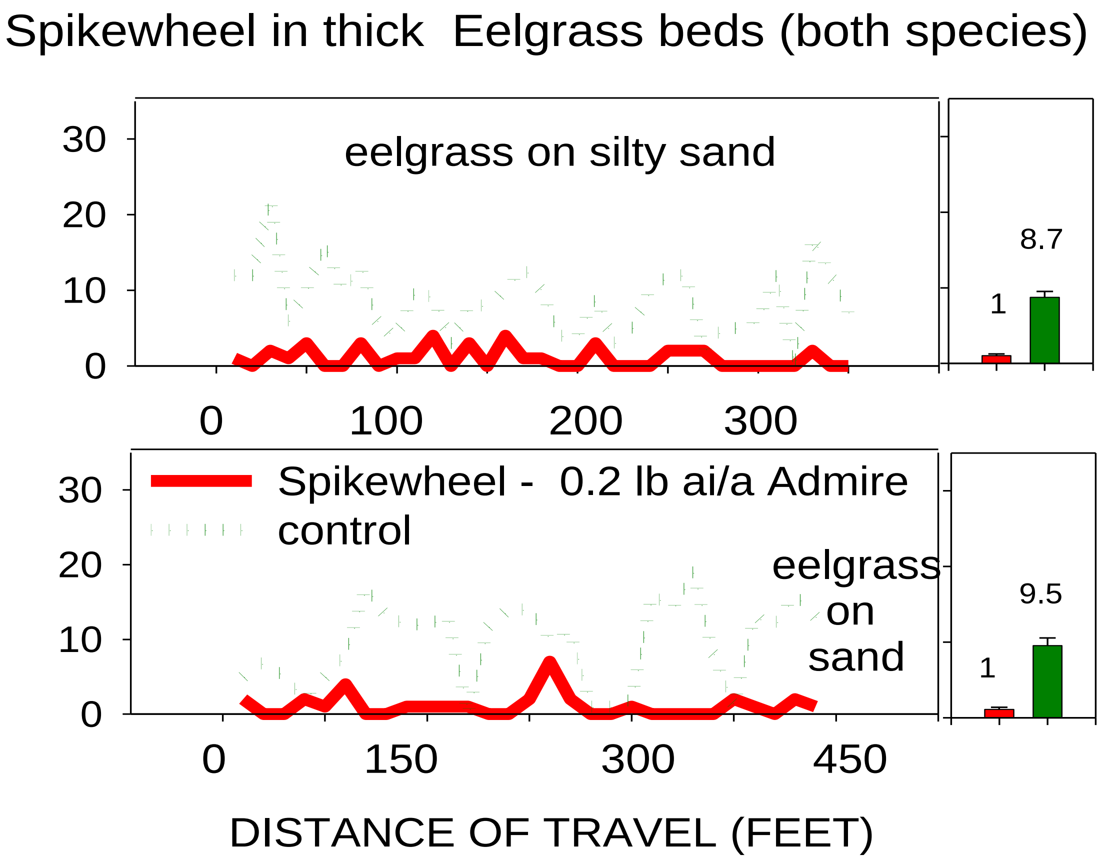


Figure 4 - 2006. Efficacy of imidacloprid (Admire) using a spikewheel injector from a barge on burrowing shrimp control in thick eelgrass beds.

Table 3 - 2007. Effect of wheel spacing on the efficacy of spikewheel-injected imidacloprid for burrowing shrimp control on May 24, 2007.

Treatment	Wheel spacing	Burrows/m^2 6/4/07 11 dat	Burrows/m^2 6/27/07 33 dat
Control		47.1±1.6	47.1±1.6
Imidacloprid 2F 0.082 lb ai/a	2 wheels/6'	10.8±2.2	27.8±2.9
Imidacloprid 2F 0. 165 lb ai/a	2 wheels/6'	3.1±0.6	18.0±1.7
Imidacloprid 2F 0.33 lb ai/a	2 wheels/6'	2.7±0.8	13.5±1.2
Imidacloprid 2F 0.125 lb ai/a	4 wheels/6'	4.3±1.2	11.9±1.0
Imidacloprid 2F 0.5 lb ai/a	4 wheels/6'	0.1±0.1	4.7±0.8

Mean of 10 1-m^2 counts ± standard error (ss3 2007)

Table 4 - 2007. Effect of wheel spacing on the efficacy of spikewheel-injected imidacloprid for burrowing shrimp control on August 14, 2007.				
				Burrows/m^2
Treatment			Wheels per 6 foot swath	9/27/2 (30 DAT)
Imidacloprid 2F	0.37	lb ai/a	4	2.9
Imidacloprid 2F	0.5	lb ai/a	6	3.7
Control				30
Treatment Prob(F)				0.0005

Mean of 10 - 1 m^2 counts ± standard error (ss11b 2007)

Table 5- 2007. Efficacy of spikewheel-injected imidacloprid on June 21 2007 for burrowing shrimp control on bare sand in large plots.								
			Burrows/m^2					
			6/26/2007		7/11/2007		9/8/2007	
Treatment			5 DAT		12 DAT		79 DAT	
Imidacloprid 2F	0.25	lb ai/a	25.6	±11.2	5.1	±1.8	18.5	±3.4
Imidacloprid 2F	0.5	lb ai/a	18.4	±7.2	2.5	±0.8	7.4	±1.9
Control			100	±0	43.5	±5.6	69.7	±4

Table 6 – 2007. Efficacy comparison of broadcast and spikewheel-injected imidacloprid applied on July 17, 2007 and August 14, 2007 to control burrowing shrimp on beds covered by thick Japanese eelgrass.							
				Burrows/m^2			
				9/13/2007		9/13/2007	
Treatment				Site 1 42 DAT		Site 2 28 DAT	
Imidacloprid 2F	0.5	lb ai/a	broadcast	3.6	±1.3	23.5	±2.4
Imidacloprid 2F	0.5	lb ai/a	injection	15.6	±2.1	25.6	±3.6
Control				26.4	±3.8	34.2	±3.1
LSD (P=.05)				16.52		20.54	
Treatment Prob(F)				0.1203		0.2829	

Mean of 10 1 m^2 counts ± standard error (ss10ab &b)

Table 7 - 2007. Effect of sediment type on the efficacy of spikewheel injecting and broadcasting imidacloprid 2F on soft mud and shell-based sediment on July 11 2007.							
				Burrows/m^2			
				9/11/2007			
				93 dat			
Treatment				Mud		Shell	
Control				28.7	±2.6	2	±0.8
Imidacloprid 2F	0.25	lb ai/a	injected	20.0	±3.1	0	±0
Imidacloprid 2F	0.5	lb ai/a	injected	16.4	±3.4	1.1	±0.7
Imidacloprid 2F	0.25	lb ai/a	broadcast	12.6	±1.5	0.8	±0.2
Imidacloprid 2F	0.5	lb ai/a	broadcast	2.0	±1.3	1.0	±0.5

Mean of 10 1 m^2 counts ± standard error (ss8 07)

Table 8 - 2008. Comparison of application methods on the efficacy of 0.5 lbs ai/ac imidacloprid for reducing burrow density from spikewheel injection and broadcast spraying*				
	Burrows in control (#/m^2)	% Reduction in burrows		
		Treatment		
Sediment condition/timing		Spikewheel - ATV	Spikewheel - Boat	Spray
Sand - April	24	16		62
Sand - May	24	72		62
Sand - July	24	83		96
Sand - September	24	25		95
Silt- June	79		0	49
Sand - June	18		0	96
Eelgrass & sand - August	11	48	74	37
Eelgrass & sand - August	28		0	9
*Each row represents a different experiment. Data are average counts across all replications				

Table 9 - 2008. Effect of timing on the efficacy of 0.5 lbs ai/ac imidacloprid from spikewheel injection *for reducing burrow density on thick eelgrass plots.			
		% reduction in burrows	
	Burrows in control	July	August
Treatment- sediment	(#/m^2)	83	
Spikewheel - eelgrass	12	87	
Spikewheel - eelgrass	13		17
Spikewheel - eelgrass	29		72
Spikewheel - eelgrass	11		0
Spikewheel - eelgrass	28		0
*Each row represents a different experiment. Data are average counts across all replications			

Table 10 -2008. Effect of timing on the efficacy of 0.5 lbs ai/ac imidacloprid for reducing burrow density from broadcast spraying and spikewheel injection.*							
	Burrows in control	% reduction in burrows					
		Time of treatment					
Treatment- sediment	(#/m^2)	April	May	June	July	August	Sept.
Spray - bare sand	25	52	52		84		92
Spray - bare sand	50		0				
Spray - bare silt	30			0			
Spray - bare sand	48						82
Spray - bare sand	47						95
Spray - bare sand	52						69
Spray - bare sand	20			95			
Spray - bare sand	76						92
Spray - bare silt	15					87	
Spray - bare silt	15						93
Spray - bare silt	72						61
Spikewheel - bare sand	25	20	72		84		20
Spikewheel - bare sand	8	63					
Spikewheel - bare sand	46		93				
Spikewheel - bare sand	20		75				
Spikewheel - bare silt	30			0			
Spikewheel - bare silt	15					0	
Spikewheel - bare silt	30						77
*Each row represents a different experiment. Data are average counts across all replications							

Table 11- 2008. Effect of eelgrass control with imazamox on the efficacy of 0.5 lbs ai/ac imidacloprid for reducing burrow density from broadcast spraying the 2F formulation.*			
		% reduction in burrows	
Treatment	Burrows in control (#/m^2)	Eelgrass treated with imazamox	Untreated eelgrass
Eelgrass treated 5/21; Shrimp treated 6/25	52	73	36
Eelgrass treated 5/21; Shrimp treated 9/16	57	95	42
*Each row represents a different experiment. Data are average counts across all replications			

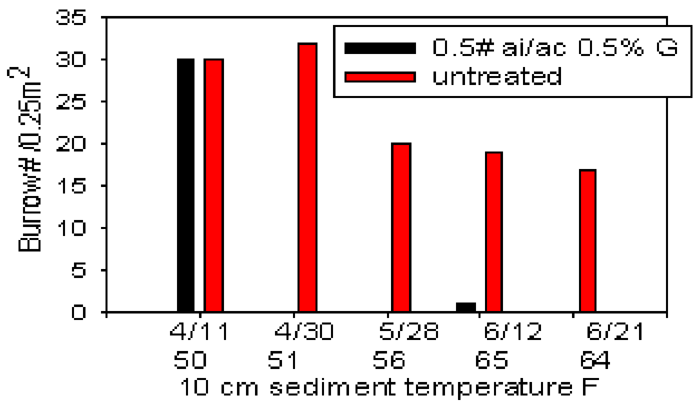


Figure 6 - 2009. Application timing/sediment temperature effect on efficacy in 2009; granular imidacloprid applied to bare sand.

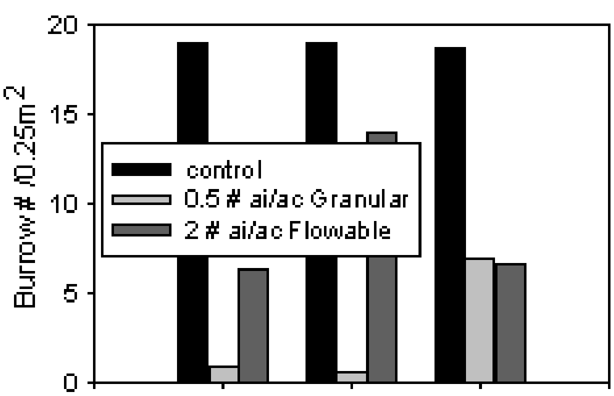


Figure 7 - 2009. Formulation comparisons at three sites where product was applied in 3” to 12” of outgoing tidal water on bare sand in 2009.

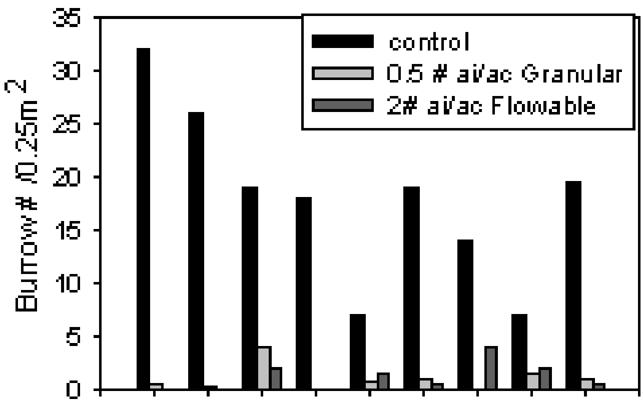


Figure 8 - 2009. Formulation comparisons at nine sites in 2009 on bare, fairly dry tidal flats.

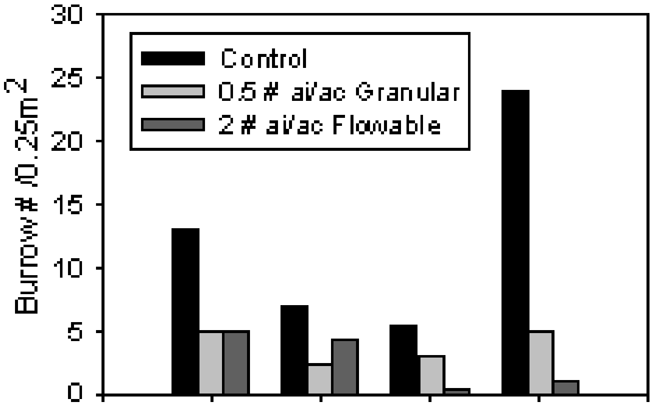


Figure 9 - 2009. Formulation comparisons at four sites in 2009 with thick Japanese eelgrass.

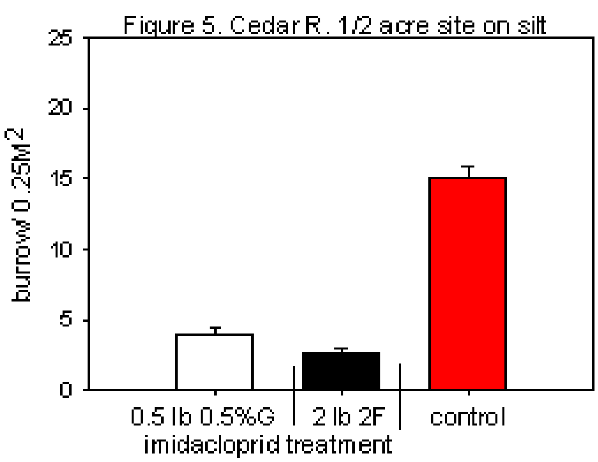


Figure 10 - 2009. Formulation comparisons at Cedar River on site – ½ acre plots in 2009.

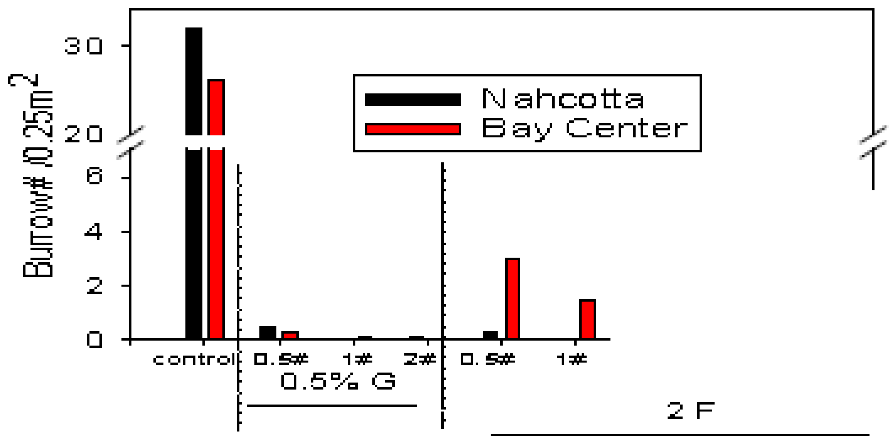


Figure 11 - 2009. Imidacloprid formulation comparisons for efficacy in May 2009 at Nahcotta and Bay Center on sand.

Table 12 - 2010. Effect of sediment type on efficacy		
	Range in % control (# of viable treatments resulting in <8 burrows/m^2)	
Sediment	Mallet (0.5 lb ai/ac)	Nuprid (2 lb ai/ac)
Bare sand	64 to 100% (8 of 13 treatments adequate)	74-100% (7 of 8 treatments adequate)
Silt	75-85% (4 of 7 treatments adequate)	97-100% (8 of 9 treatments adequate)
Silty Sand	54-86% (3 of 7 treatments adequate)	84-99% (6 of 6 treatments adequate)
Eelgrass/sand	59-90% (3 of 5 treatments adequate)	72-97% (3 of 3 treatments adequate)
*Only standard application protocol considered: June to August, minus tide with water just off		

Table 13 – 2010. Effect of sediment type and time of application on efficacy of imidacloprid for control of burrowing shrimp at Leadbetter, Willapa Bay 2010

Leadbetter - silt

Month of treatments	Burrows/m^2 Mallet (0.5 lb ai/ac)	Burrows/m^2 Nuprid (2 lb ai/ac)
April	4	0
May	1	0
July	4	0
August	20	8
* Untreated site had 16 burrows/m^2		

Leadbetter - wet sand with water flowing off

Month of treatments	Burrows/m^2 Mallet (0.5 lb ai/ac)	Burrows/m^2 Nuprid (2 lb ai/ac)
April	6	3
May	12	2
July	8	0
August	20	5
* Untreated site had 40 burrows/m^2		

Leadbetter- dry sand

Month of treatments	Burrows/m^2 Mallet (0.5 lb ai/ac)	Burrows/m^2 Nuprid (2 lb ai/ac)
April	4	0
May	6	0
July	2	1
August	4	0
* Untreated site had 16 burrows/m^2		

Leadbetter - wet silt sand with water flowing off

Month of treatments	Burrows/m^2 Mallet (0.5 lb ai/ac)	Burrows/m^2 Nuprid (2 lb ai/ac)
April	10	0
May	10	2
July	4	0
August	20	0
* Untreated site had 64 burrows/m^2		

Table 14- 2010. Effect of timing of imidacloprid (0.5 % G Mallet @ 0.5 lb ai/ac) on efficacy on sand sediment in Nahcotta

Month of treatment	Burrows/m^2 Bare sand	Burrows/m^2 Eelgrass over sand
May	12	17
June	8	11
Untreated site had 32 burrows/m^2		

Table 15. - 2010. Effect of timing of imidacloprid (0.5 % G Mallet @ 0.5 lb ai/ac and Nuprid @ 2 lbs ai/ac) on efficacy on silt sediment at Bay Center.

Month of treatment	Burrows/m^2 Mallet (0.5 lb ai/ac)	Burrows/m^2 Nuprid (2 lb ai/ac)
May	14	1
June	10	1
*untreated site had 50 burrows/m^2		

Table 16- 2010. Effect of timing of imidacloprid (0.5% G Mallet @ 0.5 ai/ac and Nuprid @ 2 lbs ai/ac) on efficacy on silt sediment at Cedar River		
	Burrows/m^2	
Month of treatment	Mallet (0.5 lb ai/ac)	Nuprid (2 lb ai/ac)
April	72	1
May	4	0
August	8	2
Untreated site had 72 burrows/m^2		

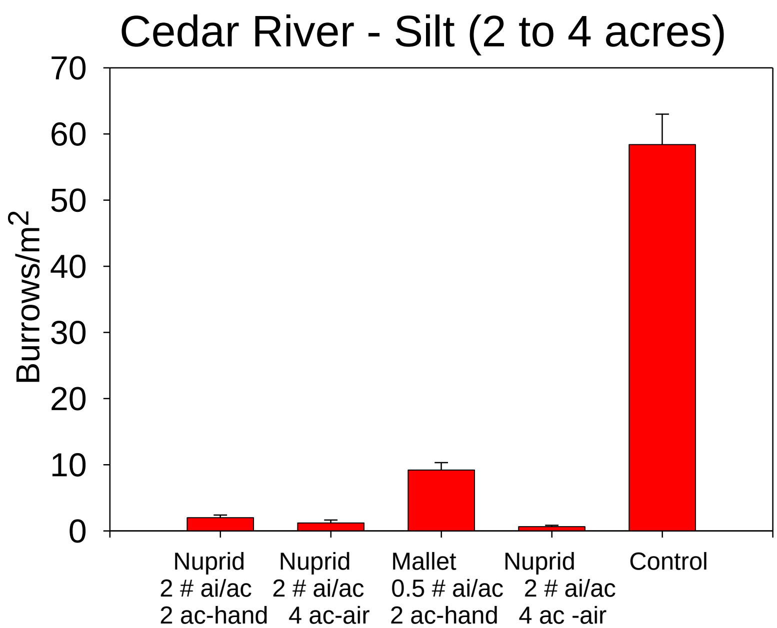


Figure 12 - 2010. Efficacy of different imidacloprid formulations on medium size plots on silt at Cedar River.

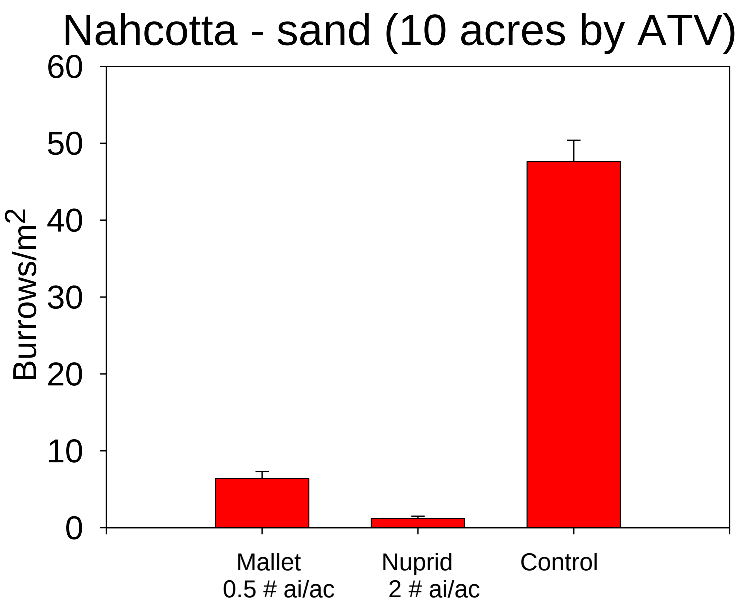


Figure 13 - 2010. Efficacy of different imidacloprid formulations on ten-acre plots on sand at Nahcotta.

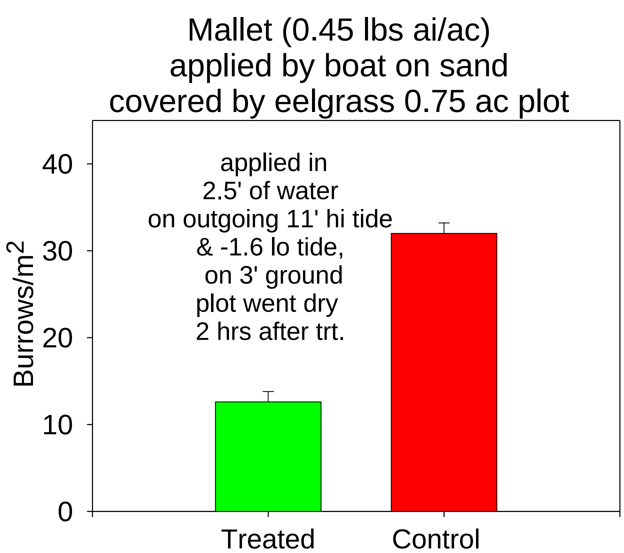


Figure 14 - 2010. Efficacy of granular imidacloprid applied from a boat during an outgoing tide.

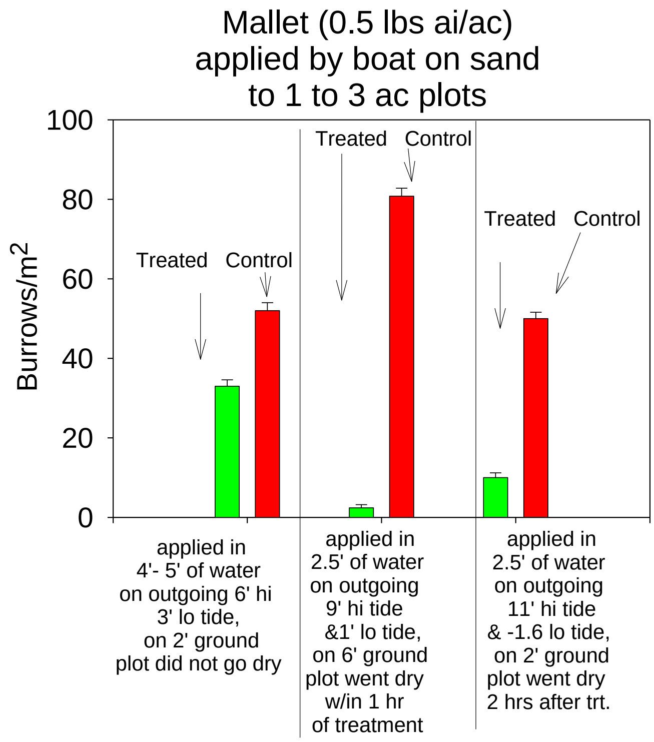


Figure 15 – 2010. Efficacy of granular imidacloprid applied from a boat during different tidal conditions.

Table 17- 2011. Efficacy of imidacloprid at 0.5 lbs ai/ac for burrowing shrimp control in 2011								
Exp #	Material	Bed Type[a]	App. Method	Acres treated	Treat-ment date	Pre-treatment density [b] (#/0.25m^2)	Post-treatment density (#/0.25m^2)	% reduction (control)
1	Mallet	Sn Zj	ATV	1	5/17/11	4.9	1.4	70
2	Nuprid	Sn Zj	ATV	1	5/18/11	6.9	1.5	78
3	Mallet	Sn Zj	ATV	1.7	5/17/11	5.7	3.3	50
4	Nuprid	Sn Zj	ATV	1.7	5/18/11	7	1.6	74
5	Nuprid	Sn Zj	Hand	0.5	5/18/11	4.3	0.8	81
6	Mallet	Sn Zj	Hand	0.3	5/17/11	7.8	2.2	70
7	Mallet	Sn Zj	Boat	0.3	6/3/11	6.1	2.5	60
8	Mallet	Sn Zj	Hand	0.12	9/14/11	4.5	1.1	75
8	Nuprid	Sn Zj	Hand	0.12	9/14/11	4.5	2.6	42
9	Mallet	Si	Hand	0.12	5/20/11	8.4	1.8	78
9	Nuprid	Si	Hand	0.12	5/20/11	8.4	1.2	85
10	Mallet	Si	Boat	0.3	6/3/11	8.4	1.12	86
11	Mallet	Si	Hand	0.3	5/20/11	9.6	3.1	67
11	Nuprid	Si	Hand	0.3	5/20/11	9.6	1	90
12	Nuprid	Sn	Aerial	10.3	7/3/11	11.1	0.5	96
13	Mallet	Sn	Hand	2.2	6/2/11	5.2	0.9	82
14	Mallet	Sn	Aerial	10.2	7/15/11	5.4	0.57	89
15	Nuprid	Sn	ATV	10.2	7/15/11	5.2	1.2	77
16	Mallet	Si	Boat	1.4	6/6/11	6.4	2.5	61
17	Mallet	Si	Boat	4.2	8/30/11	6.7	3.5	48
18	Nuprid	Si Zm	Hand	5	8/30/11	4.9	1.9	61

[a] Sn= sandy, Si=silty, Zj *Zostera japonica*, Zm *Zostera marina*,* Efficacy-E, Imidacloprid-I, Crab- C

[b] Pretreatment counts were not always available, in which case counts from adjacent control sites were used to obtain efficacy (% control).

[c] Affected crab were any crab present across the entire treated area or within 100' around the entire plot that were exhibiting signs of tetany or were dead. Data were collected 24 hours after treatment.

Table 18 - 2012. Treatment sites and efficacy of imidacloprid at 0.5 lbs ai/ac in 2012					
Size (ac)	Date	Location	Sediment	Formulation	% Control
4.8	7/2	Nahcotta	Sand w/ eelgrass	Nuprid	75
2.3	7/2	Nahcotta	Sand w/ eelgrass	Nuprid	66
5.8	7/2	Nahcotta	Sand w/ eelgrass	Nuprid	54
2.9	7/2	Nahcotta	Sand w/ eelgrass	Nuprid	53
8.9	8/2	Bay Center	Sand w/ eelgrass	Mallet	87
8.9	8/2	Bay Center	Sand w/ eelgrass	Nuprid	80
5	8/15	Leadbetter	Sand	Mallet	33
7.5	8/15	Leadbetter	Sand	Nuprid	82
1	8/17	Cedar R.	Silt	Nuprid	61

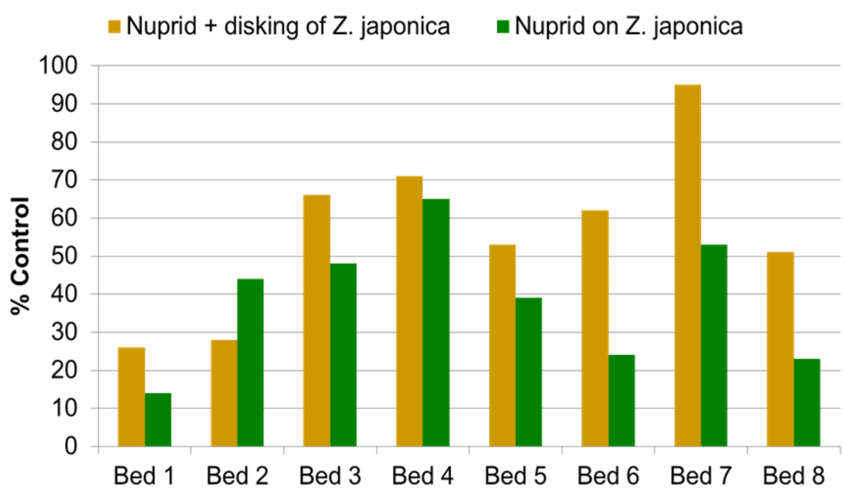


Figure 16 - 2012. Effect of post-treatment disking (1 day after treatment) on the efficacy of imidacloprid at 0.5 lbs ai/ac in 2012 applied via broadcast to sediment infested with burrowing shrimp and Japanese eelgrass.

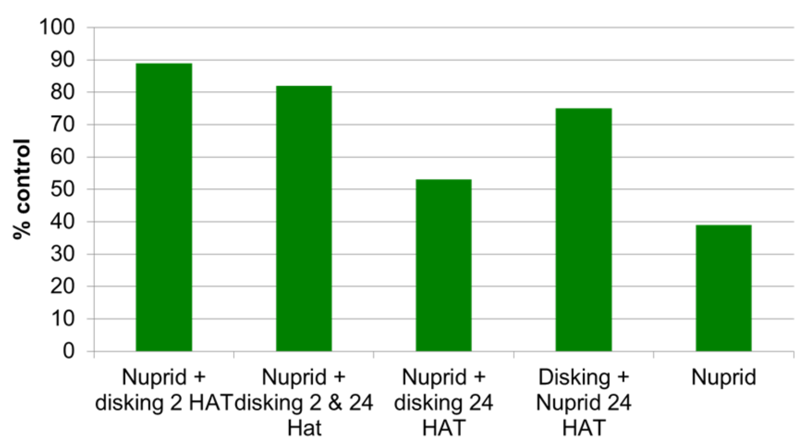


Figure 17-2012. Effect of disking time on the efficacy of imidacloprid at 0.5 lbs ai/ac in 2012 applied via broadcast to sediment infested with burrowing shrimp and Japanese eelgrass.

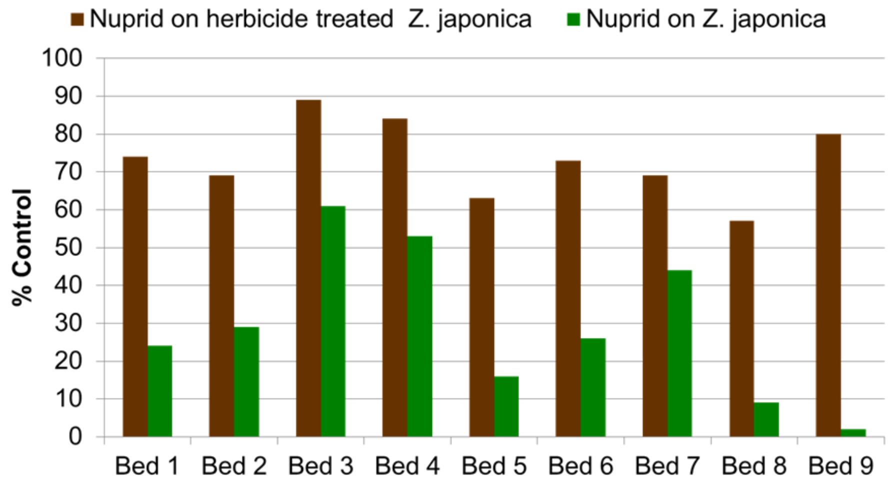


Figure 18-2012. Effect of pre-treatment control of Japanese eelgrass with imazamox on the efficacy of imidacloprid at 0.5 lbs ai/ac in 2012 applied via broadcast to beds with and without *Z. japonica* control.

Table 19- 2013. On-site treatment efficacy at SAP plots												
	Palix River sites						Leadbetter sites					
	Mallet, sparse *Z. japonica*			Nuprid thick *Z. japonica*			Mallet, bare sand			Nuprid, bare sand		
	burrows/1/4 m^2			burrows/1/4 m^2			burrows/1/4 m^2			burrows/1/4 m^2		
Stake #	1 DBT	14 DAT	% reduction	1 DBT	14 DAT	% reduction	1 DBT	14 DAT	% reduction	1 DBT	14 DAT	% reduction
1	13	0	100	15	5	67	6	0	100	3	0	100
2	19	0	100	11	4	64			0	3	0	100
3	11	0	100	16	1	94	14	0	100	5	0	100
4	14	0	80	9	3	67	18	0	100	5	1	80
5	13	0	100	4		100	20	0	100	2	0	100
6	9	3	100	15	7	53	18	3	83	5	0	100
7	13	2	100	3	1	67	18	2	89	2	0	100
8	10	0	0	10	8	20	13	1	92	1	2	0
9	11	1	100	32	7	78	11	0	100	3	0	100
10	9	2	0	22	9	59	9	1	89	2	2	0
11	9	3	100	12	4	67	4	2	50	2	0	100
12	8	2	63	9	0	100	9	0	100	8	3	63
13	14	1	100	12	0	100	9	0	100	3	0	100
14	14	1	50	15	0	100	6	0	100	2	1	50
15	5		100	11	10	9	8	0	100	1	0	100
16	16	0	100	12	2	83	15	0	100	2	0	100
17	20		100	14	9	36	10	1	90	1	0	100
18	16	0	0	10	0	100	8	0	100	1	2	0
19	18	2	83	5	4	20			0	6	1	83
20	20	0	100	11	4	64	14	0	100	2	0	100
21	21	9	67	12	4	67	9	0	100	3	1	67
22	9	0	25	20	6	70	11	0	100	4	3	25
23	9	0	100	11	3	73	17	0	100	11	0	100
24	6	0	100	10	6	40	15	0	100	11	0	100
25	6	0	64	12	1	92	11		0	11	4	64
26	7	7	100	7	1	86	11		0	3	0	100
27	14	0	33	13	4	69	11	0	100	3	2	33
28	10	0	83	14	0	100	10	0	100	6	1	83
29	12	4	60	15	6	60	12	0	100	5	2	60
30	10	6	100	7	2	71	12	2	83	2	0	100
31	9	1	71	15	10	33	11	5	55	7	2	71
32	12	1	100	12	8	33	11	2	82	4	0	100
33	13	0	80	16	3	81	4	0	100	5	1	80
34	11	0	60	16	5	69	15	0	100	5	2	60
35	8	0	100	13	8	38	11	0	100	10	0	100
36	10	1	88	7	8	0	15	0	100	8	1	88
Mean			**78±5**			**65±5**			**84±5**			**78±5**

Table 20 – 2014. Effect of Nuprid at 0.5 lbs ai/ac on young recruits on bare sand in fall 2014.				
	# burrows/0.054 m^2			
Site	Control	Treated	% control	Treatment F value
1	21.2 ±1.2	9.8±1.3	54	39
2	20.3±1.1	0.1±0.1	100	358
3	6.1±1	2.6±0.7	57	7
4	8.7±1.5	3.2±0.7	63	11
5	11.5±0.8	4.8±0.9	58	35
6	8.0±0.6	2.7±0.5	66	45
Total	12.4±0.8	3.9±0.4	76	96
Treated 10/15/13, assessed 10/31/13; F values were all significant at the 0.001% level. Assessment of just juvenile shrimp was not possible as there was a wide range of shrimp sizes (3 to 15 mm carapace). The density of small burrows was counted instead. The burrow density values reflect control of all sizes of shrimp.				

Table 21 - 2014. Summary of efficacy data from commercial sprays of imidacloprid at 0.5 lbs/ai/ac in 2014 monitored by WSU*					
		# burrow/ 0.25 m^2			
Site	Sediment/vegetation type	Before inside	After inside	After outside	% control
SAP site, liquid	Bare sand		6.28	28.9	80
	Sand w/ thick Zj		21.3	29.1	27
A 40, liquid	Sand, bare		1.6	22.7	93
	Sand, medium Zm		0.9	9.11	90
	Silty sand, bare		4.2	16.5	68
	Sandy silt, bare		1.7	61.0	97
	Silty sand, w/ thick Zm		6.0	15.3	61
	Silty sand, w/ medium Zm		2.0	7.2	72
A 101, liquid	Silt, bare	43	13.0		69
	Silt, mixed bare w/ Zm	21.7	7.1		81
B 197, liquid	Sand, bare		5.3	27.8	81
	Sand, medium to thick Zm		3.2	8.1	61
B111, granular in 5' water	silty sand	13.7	8.4		39

*Data were only collected where burrowing shrimp density was high enough to provide efficacy data. Zj – *Zostera japonica*; Zm – *Zostera marina*.

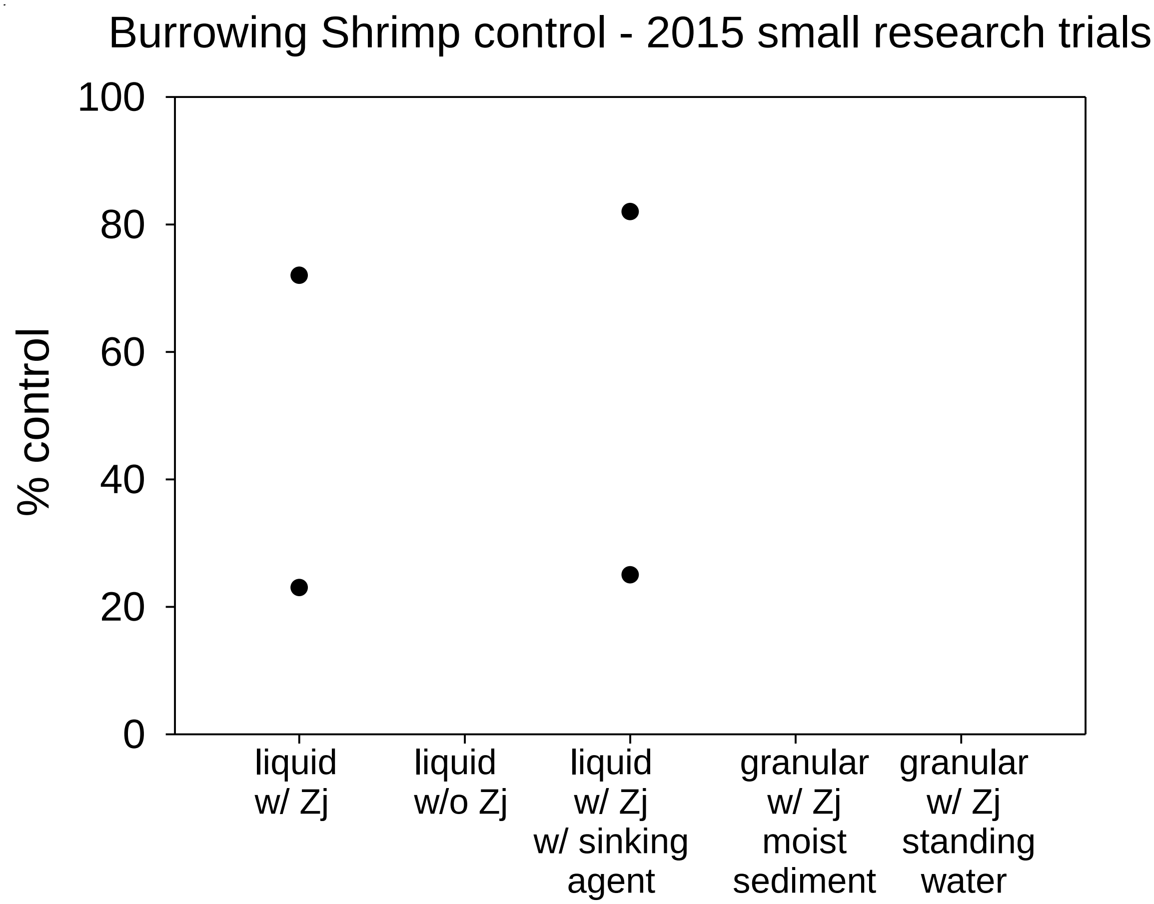


Figure 19 - 2015. Box and whisker plots of comparative control of adult ghost shrimp with imidacloprid 2F at 0.5 lbs ai/ac in early May 2015 under different treatment conditions. Experiments were conducted prior to the NPDES cancellation. The first and third quartiles are at the ends of the box, the median is indicated with a vertical line in the interior of the box, and the maximum and minimum are at the ends of the whiskers.

Table 22 – 2015. Efficacy of imidacloprid 2F hand injected at 18" depth to control burrowing shrimp in small preliminary trials in May 2015, prior to the NPDES cancellation, in areas of thick *Z. japonica.*

Treatment	% control
Imidacloprid 2F 0.5 lbs ai/ac broadcast spray	0
Imidacloprid 2F 0.5 lbs ai/ac injected	88
Imidacloprid 2F 0.25 lbs ai/ac injected	77
Imidacloprid 2F 0.125 lbs ai/ac injected	75

Appendix 2. Draft IPM recommendations for chemical control of burrowing shrimp using imidacloprid.

Background: Burrowing shrimp are located 1-3 feet below the surface of the sediment. This makes it difficult to get enough active ingredient to the target area to achieve efficacy. Consequently, burrowing shrimp control with imidacloprid can be inconsistent. Obtaining good control will be highly dependent on the site conditions during the application time, and how those conditions help or hinder the concentration of imidacloprid reaching the subsurface shrimp. Adjustments in timing, formulation and/or application method should be used to obtain higher levels of efficacy under different conditions.

Treatment Recommendations: Table 1 provides expected efficacy under various conditions. This table should be used as an IPM guide to select how to treat a site. For example, a uniform thinly vegetated site would only have the liquid formulation applied just as the water is pulling off the site. A non-uniform site could require using the liquid formulation over most of the site, but also include granular formations in the low spots, and subsurface injection on parts that are thickly vegetated.

Table 1. Draft treatment recommendations for the use of imidacloprid for control of burrowing shrimp under different conditions.

Conditions	Recommendations	Expected control (%)
Sand or silt, bare to thin eelgrass cover, relatively flat bed that dewaters uniformly	Apply imidacloprid 2F immediately after water goes off site. A large bed should be treated progressively as each section dewaters.	70 to 90
Sand or silt, bare to thick eelgrass cover, shallow swales within bed that never fully dewater and are constantly draining.	Apply imidacloprid 0.5 G by hand at low tide to areas of bed that don’t dewater.	60 to 80
Sand or silt, bare to thick eelgrass cover, basin-shaped dredged beds that never dewater at low tide.	Uniformly broadcast imidacloprid 0.5 G across bed during very low tides (<6-12” of water if possible).	60 to 80
Sand or silt, moderate to thick eelgrass cover, relatively flat bed that dewaters uniformly	Option 1- If the eelgrass is *Z. japonica*, remove with imazamox in early May. If possible *Z. japonica* should be controlled one year prior to burrowing shrimp control. In July to August, apply imidacloprid 2F immediately after water goes off site.	50 to 80
	Option 2 - Uniformly broadcast imidacloprid 0.5 G across bed in 10” to 18” of water as the tide is pulling off the site.	30 to 70
	Option 3 - Subsurface (18”) injection by hand of imidacloprid 2F*	85 to 95

Research recommendations: The major problem in achieving good consistent efficacy appears to be the inability of the current treatment protocols to move imidacloprid into the subsurface target zone where the burrowing shrimp are. Research in methods to improve efficacy has been prevented in recent years owing to a lack of NPDES, and the requirement to focus on data collection for the Sample Analysis Plan (SAP). Several other application methods may be more successful in targeting the pest, but have not been researched on treatment sites large enough to provide reliable efficacy data. The following are several protocols that should be vetted as potential methods to improve efficacy under the more challenging conditions.

<u>Situation:</u> Sites where thick eelgrass vegetation prevents imidacloprid, either the 2F or 0.5 G, from reaching the subsurface target zone when applied during low tide.

<u>Possible solutions:</u>

- *Subsurface injection by hand*:
  - Test the lowest use-rate that efficacy can be obtained with. Our current data is limited and suggests 0.125 lbs ai/ac may suffice.
  - Other parameters to test - the ideal injection spacing, and depth and volume of injection.
- *Broadcast applications of imidacloprid 2F in water:*
  - Test hand broadcast applications of imidacloprid in a 10' to 15' wide band of shallow water (3" to 6"deep) parallel to shore just as the bed dewaters during an out-going tide. The treatment pattern would progress outward as the bed continues to dewater. This protocol would theoretically let imidacloprid penetrate below the canopy in the water column and be sucked into the sediment as the bed goes dry.
  - Other parameters to test - the width and length of the treatment band, ideal water depth during application and the treatment application volume.
- *Hand broadcast (belly grind) imidacloprid in water*
  - Test hand-broadcast applications of imidacloprid 0.5 G in 15 to 20' wide-band of water (12 to 18" deep) parallel to shore just as the bed dewaters during an out-going tide. The treatment pattern would progress outward as the bed continues to dewater. This protocol would theoretical let imidacloprid pellets penetrate through the eelgrass canopy below the bed dewatered. Smaller replicated plot work indicated that this could be successful, but it has not been assessed on a commercial scale.
  - Other parameters to test - the width and length of the treatment band, and ideal water depth during application.
- *Pre-treatment of the site with imazamox to remove invasive eelgrass.*
  - Test at the commercial scale if removal of Z. *japonica* in April with imazamox improves the efficacy of a summer-applied imidacloprid 2F. This protocol has been tested in small replication plots and found to improve efficacy, but not on larger sites.
  - Other parameters to test – the timing of the imazamox treatment relative to the imidacloprid treatment.

<u>Situation:</u> Basin-shaped dredged beds that don't dewater, or slowly dewater and are covered in vegetation. These sites are common in Willapa and we have almost no efficacy data for imidacloprid 2F or 0.5 G. Normally imidacloprid applied during outgoing tides drains off the site long before it can reach the subsurface sediment.

<u>Possible solutions:</u>

- *Subsurface injection by hand*:
  - Test the lowest use-rate that efficacy can be obtained with. Our current data is limited and suggests 0.125 lbs ai/ac may suffice.
  - Other parameters to test - the ideal injection spacing, and depth and volume of injection.

A review of the past decade of research on non-chemical methods to control burrowing shrimp

Kim Patten, WSU Long Beach Research and Extension Unit

Biological control

- C*rab* – Dungeness Crab and Red Rock Crab were assessed for their potential to control adult burrowing shrimp. Adult crabs were placed in fenced enclosures in areas with high ghost shrimp burrow counts. Studies were conducted in both the winter and summer. Predation was observed over a 2 to 7 day period. There was a 5 to 25% to reduction in burrow counts. Total burrow counts, however, were still extremely high (>100/m^2) even after 7 days of enclosure. These results indicated that predation on adult burrowing shrimp was insufficient to provide any practical control.

- *Green Sturgeon* - Sturgeon were assessed for their ability to reduce adult burrowing shrimp density. Comparisons in burrow density inside and outside of areas staked to exclude green sturgeon were compared. Differences were noted, but not enough to warrant consideration for biological control. Densities of burrowing shrimp immediately within a sturgeon feeding pit and outside the feeding pit were compared. Some reduction was noted, but there were still adult shrimp remaining within the feeding pit. Comparative surveys of the densities of sturgeon feeding pits were made between commercial shellfish beds and open tideflats. There was minimal use of shellfish beds by green sturgeon compared to adjacent non-shellfish tideflats.

- *Parasitic isopods* – A bopyrid isopod parasite, *Orthione griffenis*, introduced in the 1980s from Asia, caused the collapse of west coast mud shrimp (*Upogebia pugettensis*) populations. Another isopod parasite has been noted on ghost shrimp but has had no effect on its populations.

Mechanical and cultural control

- *Suction harvesting method:* Several suction head devices were designed and hooked up to water pumps. The premise was to create enough suction to selectively evacuate shrimp from their burrows, without removing sediment. The best design (shown in the figure below) was fashioned from 33 gallon plastic barrels cut longitudinally and attached to a sharp-edged plywood platform. We were able to apply enough suction to collapse the barrels, and could selectively pull large volumes of water out of burrows, but few shrimp were removed from their burrows. We concluded that suction is not a feasible method for shrimp control. Not only was it destructive to the benthic environment, but it failed to remove a significant number of adult shrimp.

- *Subsurface air bubble harvester*: The premise of an air bubble harvester is to put enough air below the shrimp to force them up out of their burrows into the water column, where they are then trapped in a net or other harvest device. Two devices were constructed (see picture below). One used compressed air at 10.7 CFM @ 125 psi applied through our six-wheel spikewheel unit. The other used 185.5 CFM @ 100 psi applied through a large shank system constructed by an Oysterman, Leonard Bennett. The first system was tested using WSU's spikewheel barge; the second system was tested using a commercial shellfish barge (see photo below). Based on data from underwater cameras, there was no evidence that any shrimp were raised from the substrate. Burrow counts post-treatment were temporarily reduced 39% with the high volume air bubble method (60 vs. 98 burrows/m^2), but this level is still well above what is required for a successful control.


- Surface cover: Thin quick drying cement layers were set over infested areas. Although these layers set quickly, they were not effective in reducing shrimp (see photo). Plastic traps were placed over areas infested with burrowing shrimp for 1, 3 and 10 days. Although the areas under the traps went anoxic, the shrimp populations were not significantly reduced. A previous effort to use a thick cover of oyster shells was also concluded to be ineffective.

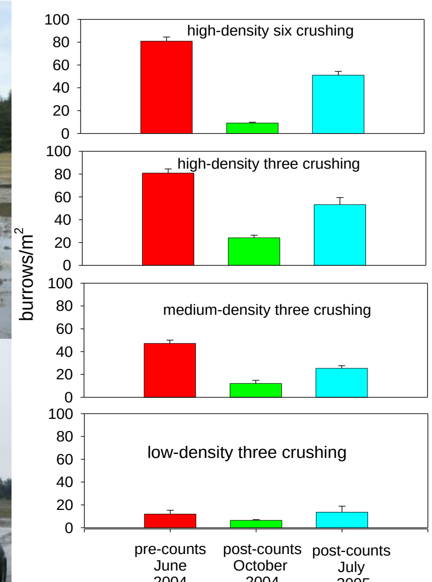
- Heat: Surface areas of sediment were heated with a propane torch for 2 minutes/m^2. The sediment temperatures at 10 cm and 20 cm depths did not change sufficiently to affect burrowing shrimp. There was no effect on adult shrimp below the heated area.

- Electrofishing: Similar equipment to that used for electrofishing was assessed for burrowing shrimp control. Experiments were done in the lab by USDA. Burrowing shrimp retreated deeper into their burrows following the introduction of electric current. The treatment was not effective in removing shrimp from their burrows or killing them.

- High pressure low-volume water injection. A shanking system was designed to inject water at 1500 PSI and be dragged through the sediment (see photo). Penetration of the water jet into the sediment was not deep enough to reach shrimp. The system did not reduce shrimp densities.

- Low pressure – high volume water injection. Taylor Shellfish designed a tow sled that injected water at ~ 10,000 gpm into the sediment. This large injection sled was very difficult to tow in a straight line and the barge was not able to maintain the plotted course of direction. An assessment of post-treatment efficacy indicated good shrimp control in the affected areas, but the entire sediment profile, vegetation and invertebrate population were also destroyed. Overall this method was not practical to implement and extremely destructive to the habitat.

- Crushing: Several amphibious platforms were assessed for compaction of sediment and killing shrimp. A four-wheeled Rolligon and a tracked unit (see photos) were repeatedly driven over affected ground and population changes of shrimp were monitored over time. Crushing reduced the number of burrows/m^2 in the year of treatment, but one year after treatment burrow density rebounded well above the 10 burrows/m^2 considered to be the economic threshold (See adjacent graph).

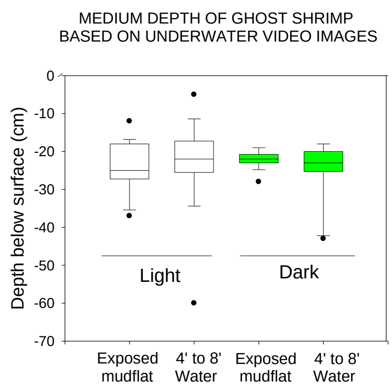


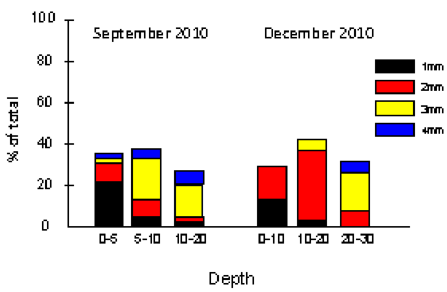
- Disking and shanking: Shallow disks and deep shanks were pulled through infected ground with either a Rolligon or ATV to control shrimp (see pictures). Neither method was effective in reducing shrimp populations.   Neither method could penetrate deep enough to affect shrimp, and both methods were destructive to eelgrass, surface sediment and oysters that were present. New efforts are focused on shallow in-water harrowing as a method to reduce the populations of new recruits as they settle. Results are pending.



- Cultural methods: There has not been any recent controlled scientific research on cultural methods. However, long-lines, floating racks and flip bag cultural methods are commonly used by growers to prevent oysters sinking in affected ground. These methods are feasible in areas of production that are protected from violent storm action, and where shrimp populations are not too high to prevent effective anchoring. These condition are not very common, so these methods are really only feasible for growers with large acres to select from. Shellfish production in Willapa is 95% ground culture and 5% off-bottom. The majority of growers don’t have viable options for switching their farms to off-bottom culture.

- Behavioral weak links.   Assessments were made to find weak links in the biology of the pest that could help focus the mechanical control effort. Burrowing shrimp were pit-tagged, as well as filmed under the surface in their burrows to determine if there was a time when they came closer to the surface. Shrimp maintained a fairly constant depth within their burrows, 25-30 cm, regardless of the conditions. Adult burrow depth, 60 to 100 cm, is deep enough to preclude most types of mechanical control (see figure on excised burrow). The depths of new recruits were sampled as a function of time and size. New recruits were often found at depths too deep to





facilitate easy physical control.

- Trapping: Scents were tested for their attractiveness to burrowing shrimp. Several were found to be effective. Scent lures were then used in crawfish traps on the sediment surface to trap adult burrowing shrimp. Although a few large male shrimp were trapped, the traps had no impact on density of shrimp in the immediate area.

- Water injection. The traditional method to harvest shrimp is by pumping water into the sediment along a bank of drainage channel. Shrimp will float out. This method is destructive to the sediment, and is only effective on channel banks and not flat shellfish ground. A method was devised to extract shrimp from small areas on flat ground by pumping water into an 8” diameter aluminum pipe sunk 1 meter deep into the sediment (see figures). It was effective for sampling but not practical for treating large areas.


- Sound Waves. Sound waves of different frequencies were assessed to determine if shrimp were sensitive to a particular Hz. No frequencies within the normal range were found to be effective. Infrasound and ultrasound could have some potential, but have yet to be fully assessed.

Summary:

Research over the past decade has examined options for nonchemical control. The table in the appendix lists most of those projects and PI’s. No suitable biological control method has yet been found to suppress the population of ghost shrimp. None of the mechanical methods assessed provided viable options for management of burrowing shrimp populations. They all failed to permanently reduce shrimp populations below the economic threshold (10 burrows/m^2). Most of the methods tested were also very destructive to the habitat, as well as to any shellfish that would be present at the time of treatment. At present the only commercial production of oysters in shrimp infested ground in Willapa Bay and Grays Harbor is in the small areas of the bays that are protected from exposure to major winter storms and have low enough shrimp densities to provide for secure anchoring for off-bottom culture. None of these production methods, however, are viable for large-scale production across the major growing regions in these estuaries.

Major research projects between 2005 and 2016 to develop alternative controls for burrowing shrimp management*		
Project/ year(s)	PIs	Summary of findings, and significance to IPM
Monitoring and general IPM		
Mapping the distribution of burrowing shrimp and their interaction with oyster aquaculture in Willapa Bay: 2006 to 2010	Dumbauld, USDA; Wecker, UW	Shrimp populations of Willapa Bay were mapped. This is useful to trend future patterns of recruit and population shifts.
Monitoring larval stages of burrowing shrimp and associated water quality variables in Willapa Bay: 2007 to 2009	Bollens, WSU Vancouver	Diurnal and tidal patterns of larvae movement in the water column were found. Could potentially help monitoring for new recruitment in the future.
Using molecular genetics to identify source populations of ghost shrimp in Willapa Bay and Grays Harbor Estuaries: 2005 to 2007	Parr, San Jose State	Not successful in identifying recruit source populations.
Rearing of juvenile burrowing shrimp from eggs: 2006	Dumbauld, USDA-ARS and UW	Not successful enough to provide samples for research.
Biological control		
Macrofauna predators (crab) as biocontrol for burrowing shrimp: 2006 to 2007	Patten, WSU	Few adult burrowing shrimp were consumed by crab under natural conditions in the wild.
Macrofauna (green sturgeon) as biocontrol for burrowing shrimp: 2006 to 2007	Trimble, UW; Patten, WSU	Green sturgeon feed on significant amounts of adult burrowing shrimp. The use of this listed species is problematic for a biocontrol agent.
Lug worm as biocontrol of burrowing shrimp: 2006	Booth, PSI	No effects on burrowing shrimp populations were found.
Identification of predators as potential biological control agents of burrowing shrimp in Willapa Bay: 2007 to 2009	Bollens, WSU Vancouver	Numerous species were found which consumed burrowing shrimp larvae. No one predator dominated enough to be a significant management tool.
Augmenting the bopyrid isopod parasite *Ione cornuta* for the biological control of its ghost shrimp host *Neotrypaea californiensis:* 2006 to 2010	Chapman, OSU	This isopod had only a minor effect on ghost shrimp. It would not be useful to manage populations.
Mechanical control		
Examination of operational parameters for electrofishing equipment to be used to control burrowing shrimp in oyster culture, a feasibility study: 2008	Dumbauld USDA-ARS	Not effective; shrimp moved deeper into their holes rather than out of their holes.
Burrowing shrimp control using sound waves: 2006, 2015	Patten, WSU; Dumbauld, USDA-ARS	Irritation noted at some high frequencies in the lab. Use in field could be problematic. Potential management tool, but use of sound wave technology has serious implications for endangered species (whales, seals etc.)

Water sled as alternative control for burrowing shrimp management : 2006 to 2008	Johnson, Taylor Resources	Partial control provided by water jet sled, but impacts to the sediment were too significant to be a valid control method.
High pressure water jets for burrowing shrimp control: 2006	Patten, WSU	Water jet penetration not deep enough for efficacy.
Harvest & harrowing systems for control of newly recruited burrowing shrimp: 2006, 2015, 2016	Patten, WSU	In-water sediment disturbance to dislodge newly recruited shrimp followed by netting. Results to date have not been effective. New efforts are continuing. Method would not be useful for management of adult shrimp.
Mechanical compaction for control of burrowing shrimp: 2004 to 2007	Patten, WSU	Compaction of shrimp-affected tideflats suppressed population for short term, but populations were back to pre-existing densities in the year after treatment.
Sediment mechanical modification for control of burrowing shrimp: 2005 to 2008, 2015 to 2016	Liou, U of Idaho; Patten, WSU	Sediments in the bay are not suitable for achieving enough compaction to kill shrimp. Applying a thin layer of cement did not control shrimp.
Chemical control		
Screening of alternative chemicals for burrowing shrimp control: 2004 to 2008	Patten, WSU	Organic insecticides, GRAS compounds, salts, and dozens of other chemicals were assessed for their potential efficacy. None were effective enough to warrant registration. Only imidacloprid showed promise.
Evaluation of subsurface chemical delivery systems for management of burrowing shrimp populations: 2006 to 2010	Patten & Durfey, WSU	Partial success using shanking and spikewheel technology to improve efficacy of more benign chemistries, but this methodology was too problematic to be practical.

*This list represents only some of the major work done during this time period.